Transport Canada
Development

Transports Canada
Développement

TP 8478E

Frangible Microwave Landing System Support Structures

Prepared for
Transportation
Development Centre
Transport Canada

by
Andrew Antenna Company Limited

AUGUST 1987
(Reprinted, February 1988)

Canada

FRANGIBLE MICROWAVE LANDING SYSTEM SUPPORT STRUCTURES

TP 8478E

Prepared for

Transportation
Development Centre

Transport Canada

by

R.B. Venner , P.Eng.
Andrew Antenna Company Limited

August , 1987

The contents of this report reflect the views of Andrew Antenna Company Limited which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or opinions of the Transportation Development Centre of Transport Canada.

Un sommaire en français de ce rapport est inclus avant la table des matières.

Transport Canada / Transports Canada
Development / Développement

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 8478E	6729/30/31	

4. Title and Subtitle	5. Report Date
FRANGIBLE MICROWAVE LANDING SYSTEM SUPPORT STRUCTURES	August 1987
	6. Performing Organization Report No.
7. Author(s)	8. Transport Canada File No.
RON B. VENNER, P.ENG.	D1455-179
9. Performing Organization Name and Address	10. DSS File No.
ANDREW ANTENNA COMPANY LIMITED 606 BEECH STREET WHITBY, ONTARIO L1N 5S2	T8200-6-6520/01-NG
	11. DSS or Transport Canada Contract No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
TRANSPORTATION DEVELOPMENT CENTRE (TDC) 200 DORCHESTER BLVD. WEST, WEST TOWER, SUITE 601 MONTREAL, QUEBEC H2Z 1X4	14. Sponsoring Agency Code
15. Supplementary Notes	16. TDC Project Officer
	C.A. Versailles

17. Abstract

A two-part study has been conducted into the design requirements for a frangible Microwave Landing System (MLS) support structure. Part I is a specification which establishes the structural design requirements and the impact test procedures. Part II is a presentation of the study undertaken to develop the specification. The study includes a comparative analysis of environmental and service condition requirements leading to recommendations of wind velocity and ice thickness specifications for use in structural design. Strength and stiffness requirements can be proven using linear static analysis; however, analysis of aircraft impact loads will require development of computer programs to include time dependent loading and non-linear material properties. Frangibility concepts were researched and categorized in three main types of design; frangible connection design, frangible member design, and frangible mechanism design. Impact testing was conducted on aluminum bolted members representing frangible connection design, and glass fiber reinforced polyester members representing frangible member design. Test results indicate that the immediate needs for a frangible support structure can be satisfied using low mass, high stiffness aluminum members connected with brittle aluminum fasteners, but that the ultimate frangible design will use members of fiber reinforced plastic with carefully designed "built-in" break points.

18. Key Words	19. Distribution Statement
STRUCTURES, FRANGIBLE, IMPACT TESTS MLS SUPPORTS	A limited number of copies are available from the Transportation Development Centre

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Unclassified	Unclassified	59	

TDC CDT 79-005
Rev 86

Canada

Transports Canada / Transport Canada

Développement / Développement

FORMULE DOCUMENTAIRE DU RAPPORT

1. Nº du rapport Transports Canada	2. Nº de l'étude — CDT	3. Nº de catalogue du destinataire
TP 8478 E	6729/30/31	

4. Titre et sous-titre	5. Date du rapport
FRANGIBLE MICROWAVE LANDING SYSTEM SUPPORT STRUCTURES	Aout 1987
	6. Nº du rapport de l'organisme exécutant

7. Auteur(s)	8. Nº de dossier Transports Canada
RON B. VENNER, P.ING.	D1455-179

9. Nom et adresse de l'organisme exécutant	10. Nº de dossier — ASC
ANDREW ANTENNA COMPANY LIMITED 606 BEECH STREET WHITBY (ONTARIO) L1N 5S2	T8200-6-6520/01-NG
	11. Nº de contrat — ASC ou Transports Canada

12. Nom et adresse de l'organisme parrain	13. Genre de rapport et période visée
CENTRE DE DEVELOPPEMENT DES TRANSPORTS 200 OUEST BOULEVARD DORCHESTER, SUITE 601-TOWER OUEST. MONTRÉAL (QUÉBEC) H2Z 1X4	14. Code de l'organisme parrain

15. Remarques additionnelles	16. Agent de projet — CDT
	C.A. versailles

17. Résumé

Une étude en deux parties a été réalisée concernant les exigences de conception d'une structure de soutien frangible pour un système d'atterrissage hyperfréquences (MLS). La partie N°1 est une spécification qui établit les exigences de conception structurelle et les procédures d'essai au choc. La partie N°2 est une présentation de l'étude entreprise pour la mise au point de la spécification. Cette étude comprend une analyse comparative sur les exigences des conditions de fonctionnement et d'environnement conduisant à des recommandations sur la vitesse du vent et l'épaisseur de glace destinées à être utilisées lors de la conception structurelle. Les exigences concernant la résistance et la rigidité peuvent être vérifiées grâce à une analyse statique linéaire; toutefois, l'analyse des contraintes de choc d'un aéronef exigeront la mise en place de programmes informatiques pour introduire les notions de contraintes fonction du temps et les propriétés non linéaires des matériaux. Les concepts de fragilisation ont été rescherchés et classés en trois principaux types de conceptions: conception des liaisons frangible, conception des éléments frangible, et conception des mécanismes frangible. Il résulte des essais que les besoins immédiats d'une structure de support frangible peuvent être satisfaits en utilisant des éléments légers, en aluminum de haute rigidité, reliés entre eux par des fixations en aluminium cassant, mais que la structure frangible définitive sera composée d'éléments en plastique renforcé de fibre de verre et comportant des points de rupture "intégrés" soigneusement étudiés.

18. Mots-clés	19. Diffusion
STRUCTURES, FRANGIBLE, ESSAIS DE CHOC, SUPPORT DE SYSTÈME D'ATTERRISSAGE HYPERFREQUENCES MLS.	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22 Nombre de pages	23. Prix
non classifié	non classifiée	59	

CDT/TDC 79-005 Rev 86

Canada

PREFACE

In order to develop improved operation techniques and airport facilities, emphasizing increased safety for aircraft and passengers, the Transportation Development Centre of Transport Canada contracted Andrew Antenna Canada Limited (AACL) to conduct a study into the design requirements for frangible MLS support structures. The report contained herein presents the results of all phases of the study.

AACL wishes to express its appreciation to Mr. Derek Ansell of Transport Canada for his assistance in the preparation of this report. In addition AACL would like to acknowledge the efforts of Mr. Stephen A. Cannistra of the Federal Aviation Administration for his guidance and information provided resulting from several years experience in frangible design of airport structures.

SUMMARY

1. Introduction

As part of a design and manufacturing contract from Supply and Services Canada on behalf of Transport Canada for a Microwave Landing System (MLS) Frangibility Study, Andrew Antenna Company Limited has prepared a report on design requirements for a frangible MLS support structure.
The report has been written in two parts. Part I is a design specification for frangible MLS support structures. Part II is the frangibility study undertaken to develop input to the specification in Part I.

2. Part I - Design Requirements for Frangible Microwave Landing System (MLS) Support Structures

The specification was written to outline design criteria for environmental loading, and the general requirements for frangible design and testing. Included are the specific wind and ice loading requirements for survival and operating conditions, along with allowable stresses and deflection limits. The objectives for static and impact testing of frangible devices are also specified.

3. Part II - Design Requirement Study For Frangible MLS Support Structures

The requirements of the study were to examine the general design criteria regarding items such as environmental loading conditions, jet blast and effects of aircraft impact, plus to investigate various frangibility concepts including impact testing of selected frangible devices.

3.1 MLS Support Structure Requirements

A comparison of Transport Canada document DFS 1000 was made against applicable CSA (Canadian Standards Association) and FAA (Federal Aviation Administration) documents regarding wind and ice loads for the support structure. The conclusion made was that wind velocities and ice thickness specified in DFS 1000 are too severe for frangibly designed structures. A recommendation was made to use the environmental conditions of DFS 1000 but to use wind and ice loading more consistent with CSA Standard S37 "Antenna Towers and Antenna-Supporting Structures".

With regard to impact loading of the support structure, the study recommends that either commercially available or specially written computer codes be examined as a means of analysing the effects of aircraft collison.

3.2 Frangibility

The study presents the results of literature searches, and discussions with FAA and DOT personnel regarding frangibility concepts. Three basic concepts were examined which include; frangible connection design, frangible member design, and design using frangible mechanisms. Each concept has its own advantages and disadvantages which were considered with respect to the requirements of the MLS support structure.

3.3 Impact Testing

A limited testing program was undertaken to evaluate a particular type of frangible connection using aluminum bolts, and a frangible member concept using glass fiber reinforced polyester angle. A pendulum type impactor was designed and used for testing the frangible devices to determine the amount of energy absorbed by the break away mechanism. It was concluded from testing that in order to meet the immediate needs for an MLS support structure, where frangibility requirements were secondary, that the frangible connection design using stiff, light weight, low toughness members fastened with aluminum bolts would be the best solution. It was also evident from testing that frangible member design, using some type of reinforced plastic member with pre-determined break points positioned along its length would produce a better frangible design, pending an extensive testing program.

SOMMAIRE

1. Introduction

Dans le cadre d'un contrat de conception et de fabrication reçu du Ministere Approvisionnements et Services pour le compte de Transports Canada pour l'étude de fragilisation d'un système MLS, Andrew Antenna Company Limited a préparé un rapport sur les exigences de conception pour une structure de soutien frangible d'un système d'atterrissage hyperfréquences. Le rapport a été établi en deux parties. La partie N°1 est une spécification de conception pour des structures de soutien d'un système d'atterrissage hyperfrequénces. La partie N°2 est l'étude de fragilisation entreprise pour collecter les données nécessaires à l'établissement de la spécification contenue dans la partie N°1.

2. Partie N°1 - Exigences de conception pour des structures de support d'un système d'atterrissage hyperfréquences (MLS).

La spécification a été établie pour mettre en évidence d'une part, les critères de conception en fonction des contraintes de l'environnement, et, d'autre part, les exigences générales pour une conception frangible et pour les essais. Cette spécification reprend également les exigences spécifiques dues au vent et à la glace pour des conditions de survie et de fonctionnement, ainsi que les limites de flexion et de contrainte admissibles. Les objectifs des essais statiques et de choc y sont également spécifiés.

3. Partie N°2 - Étude des exigences de conception de structures frangible d'un système d'atterrissage hyperfréquences (MLS).

Cette étude nécessitait l'examen des critères généraux de conception concernant en particulier des problèmes tels que les contraintes dues à l'environnement, au souffle des jets et aux effets du choc d'un aéronef, ainsi que l'étude des divers concepts de fragilisation, y compris les essais d'impact des dispositifs frangible retenus.

3.1 Exigences concernant la structure de support d'un système d'atterrissage hyperfréquences.

Nous nous sommes livrés à une comparaison entre le document de Transports Canada référencé DFS 1000 et les documents applicables de l'ACNOR (Association Canadienne de Normalisation) et de l'AFA (Administration Fédérale de l'Aviation) concernant les contraintes dues au vent et à la glace pour la structure de suppport. Notre conclusion est que les vitesses de vent et les épaisseurs de glace spécifiées dans le document DFS 1000 sont trop strictes

pour des structures conçues pour leur fragilisation. Nous avons émis un avis en faveur de l'utilisation du document DFS 1000 en ce qui concerne les conditions d'environnement, mais en recommandant d'utiliser les contraintes dues au vent et à la glace de la norme ACNOR S37" Tours d'antennes et structures de support d'antennes", qui sont plus logiques. En ce qui concerne les contraintes de choc de la structure de soutien, l'étude recommande d'examiner des codes machine existant sur le marché ou écrits spécialement afin d'analyser les effets d'une collision d'aéronef.

3.2 Fragilisation

L'étude présente les résultats de recherches faites dans la littérature existante et de discussions avec le personnel de la Fédération de l'aviation civile et de la Direction des transports. Trois conceptions de base ont été étudiées: une conception basée sur des liaisons frangible, une basée sur des éléments frangible et une conception utilisant des mécanismes frangible. Chaque conception comportait ses avantages et ses inconvénients qui ont été étudiés en fonction des exigences d'une structure de soutien d'un système MLS.

3.3 Essais de chocs

Un programme d'essais limité a été lancé afin de tester un type particulier de liaison utilisant des boulons en aluminium associés à une conception d'éléments frangible composés de cornières en polyester renforcé de fibre de verre. Un appareil d'essais de résistance aux chocs à pendule a été mis au point et utilisé pour tester les parties frangible et déterminer la quantité d'énergie absorbée par le mécanisme en se brisant. Les résultats des essais ont prouvé qu'afin de répondre aux besoins immédiats en matière de structure de soutien de MLS, pour laquelle les exigences de fragilité étaient secondaires, la meilleure, solution serait une conception de liaisons frangible composée d'éléments rigides, légers, à basse résistance, reliés entre eux par des boulons en aluminum. Les essais ont également démontré clairement que, dans l'attente d'un programme d'essais plus approfondis, une conception basée sur des éléments frangible, utilisant une type d'élément en plastique renforcé et comportant des points de ruptures prédéterminés sur sa longueur, donnerait une meilleure conception frangible.

TABLE OF CONTENTS

PREFACE v

SUMMARY vii

PART I

Design Requirements for
Frangible Microwave Landing System (MLS)
Support Structures

PART II

Design Requirement Study For
Frangible MLS Support Structures

PART I

DESIGN REQUIREMENTS FOR FRANGIBLE MICROWAVE LANDING SYSTEM (MLS) SUPPORT STRUCTURES

PART I

TABLE OF CONTENTS

SECTION		PAGE
1.	INTRODUCTION	1
	1.1 Scope	1
	1.2 Definitions	1
	1.3 Intended Use	1
2.	APPLICABLE DOCUMENTS	2
3.	REQUIREMENTS	2
	3.1 General	2
	3.2 Environmental Service Conditions	3
	3.3 Wind and Ice Loading	3
	3.3.1 Survival Loads	3
	3.3.2 Operating Loads	4
	3.4 Allowable Stresses	4
	3.5 Impact Loads	4
	3.6 Foundations	5
	3.7 Guyed Towers	5
	3.8 Materials	5
	3.9 Dissimilar Materials	5
	3.10 Frangible Design	6
	3.11 Testing	6
	3.11.1 Static Load Testing	7
	3.11.2 Impact Testing	7
	3.12 Technical Reports	7

1. INTRODUCTION

This document specifies the requirements pertaining to the structural design of frangible Microwave Landing System (MLS) support structures.

1.1 Scope

The specification sets forth the design criteria for environmental loading, plus the general requirements for frangible design and testing.

1.2 Definitions

The term "frangible" as used throughout this specification refers to the ability of the structure to break apart when impacted by a colliding aircraft. A structure which exhibits good frangibility will shatter into small pieces upon impact, and cause minimum damage to the aircraft. A "frangible device" is any connection, notch, stress-raiser, or other type of discontinuity designed into the structure to function as a fracture initiation point.

When impacted it is desirable that the structure fail with a "windowing effect" whereby a section of the structure "opens up" allowing the impacting object to pass through. This type of design will result in minimum energy transfer due to mass acceleration of structural components, and will have the least effect on the flight path of the aircraft. The length of structural members shall be kept to a minimum in order to limit the possibility of members "wrapping around" or otherwise interfering with components of the colliding aircraft.

1.3 Intended Use

The support structure shall be used to raise an MLS antenna and associated equipment to a specified height above grade level. The structure must satisfy the stability requirements under operating loads and strength requirements under survival loads as stated within this specification. Since the antenna and support structure are located in the vicinity of landing and take-off zones it is required that the structure be frangible in the event of accidental aircraft impact.

2. APPLICABLE DOCUMENTS

The following publications form a part of this specification and are applicable to the extent specified herein.

CSA STANDARD S37	Antenna Towers and Antenna-Supporting Structures.
CSA STANDARD CAN3-S157	Strength Design in Aluminum.
CSA STANDARD CAN3-S16.1	Steel Structures for Buildings.
CSA STANDARD CAN3-A23.3	Design of Concrete Structure for Buildings.
DOT STANDARD DFS 1000	General Specification for Procurement of Electronic Equipment.

3. REQUIREMENTS

3.1 General

The support structure shall serve the purpose of elevating the MLS antenna and associated equipment to a height dictated by the site parameters. Design of the structure shall provide sufficient rigidity such that deflections under operating conditions do not exceed allowable limits. The structure shall meet the strength requirements as specified in CSA Standard S37 for the survival design conditions. In addition the structure shall be designed to be frangible (or break apart) in the event of accidental impact by an aircraft and shall cause minimum damage to the aircraft.

Frangibility shall be incorporated by proportioning structural members to have low mass, short length, and high stiffness properties, and by designing in break points either at connections or along the length of the member. The impact failure mode should be kept simple, with emphasis on the ability of the structure to create a windowing effect. This will minimize the amount of energy transfer from the aircraft to structural components being accelerated out of the way.

3.2 Environmental Service Conditions

The support structure shall be capable of being exposed to the environmental service conditions of DFS 1000 section 5.3.2., for Class 2 Outdoor Equipment (with the exception of wind-speed and ice loading). Wind and ice loading shall be analysed as per the requirements of sections 3.3, 3.3.1 and 3.3.2 of this specification. Selected materials and fabrication techniques shall be shown by testing or from published data, to be capable of withstanding environmental weathering for 20 years. No operational or structural degradation shall be permitted within this period.

3.3 Wind and Ice Loading

Analysis of wind and ice loading for the support structure shall be in accordance with the requirements of CSA Standard S37 section 3.2. Wind loads shall be applied to the support structure and antenna in the directions which will produce the maximum loads in the structure. The magnitude of the wind load shall be derived from the reference velocity pressure q, and can be related to wind velocity by the expression.

$$q = 1/2 \rho v^2$$

where: ρ = density of air = 1.2929 kg/m^3
v = wind velocity m/s

Ice shall be considered to form radially on the surface of all exposed members. When the combined effects of wind and ice are considered, the wind force may be reduced by one half, as per clause 3.2.2 of CSA S37.

3.3.1 Survival Loads

The support structure shall be capable of sustaining survival wind and ice loads without any permanent deformation. The reference velocity pressure for the survival wind load shall be based on a 30 year recurrence interval as provided in the wind map in CSA S37 and given below:

CLASS A	450 Pa
CLASS B	600 Pa
CLASS C	850 Pa

Survival ice conditions shall be as provided for in the ice map in CSA S37 and given below:

CLASS 1	10 mm
CLASS 11	25 mm
CLASS 111	40 mm
CLASS 1V	50 mm
CLASS V	OPEN

3.3.2 Operating Loads

The support structure shall have sufficient rigidity to permit operation of MLS equipment in winds based on a 10 year recurrence interval.

The following reference velocity pressure shall apply to the wind zones in CSA S37 for operating conditions:

CLASS A	380 Pa
CLASS B	520 Pa
CLASS C	760 Pa

Ice loading shall be the same as required for the survival load case.

Wind loads on the MLS antenna shall be evaluated for wind directions which create maximum pitch, yaw and roll deflections of the antenna. The support structure shall be designed so that antenna deflections are limited to:

	MAX DEFLECTION (DEG)
PITCH	± 0.1
YAW	± 0.01
ROLL	± 0.1

3.4 Allowable Stresses

For support structures consisting of steel or aluminum material, stress levels shall not exceed those specified in CSA S16.1 or CSA S157. Allowable stresses for other materials (such as plastics or reinforced polyester etc.) shall be derived from suitable design data, and shall not exceed 1/3 of the material yield strength.

3.5 Impact Loads

Impact loads shall be based on collision forces generated by a light weight aircraft travelling at landing or takeoff speeds of 120 km/h. It is possible that any part of the aircraft may strike the tower, however the wings and landing gear should be considered the most vulnerable areas. Impact to the structure shall be considered to come from any direction and may contact the structure at any elevation.

3.6 Foundations

Foundation design for permanently located MLS support structures shall be in accordance with CSA S37 and CSA Standard, CAN3-A23.3 "Design of Concrete Structures for Buildings". Foundations shall be designed so that long term settlement will not cause permanent deflection of the MLS antenna greater than ± 3 deg. in pitch, yaw, or roll. Frangible connections shall be used to fasten the support structure to the foundation.

3.7 Guyed Towers

Towers shall be self-supporting and should avoid the use of guy wires as a means of controlling deflection. If guys are to be used in the design, they must have frangible connections at the ends plus break points at maximum spacing 1.5m along the length.

3.8 Materials

Materials shall be selected on the basis of least weight and maximum stiffness. Members with low mass will require very little energy in order to be moved out of the way of a colliding aircraft. High member stiffness will prevent energy absorbtion from flexure and will ensure a more direct transfer of energy to the frangible device. Materials can include metals, plastics or composites, providing they comply with all requirements of this specification. Steel surfaces shall be protected from corrosion by galvanizing in accordance with specification ASTM A123. Machined surfaces of stainless steel material shall be passivated to ASTM A64160. Plastic material must be ultra-violet stabilized.

3.9 Dissimilar Materials

Materials which may experience galvanic corrosion due to electrolytic incompatibility must not be placed in intimate contact.

3.10 Frangible Design

The MLS support structure shall incorporate sufficient frangibility so as to ensure a fragmented collapse of the structure when impacted. The impacting aircraft must be able to pass through the structure with minimum energy absorption by the frangible device/devices in the plane of the impact. To achieve this effect frangible devices should be located across horizontal sections of the structure and be positioned at elevations no more than 1.5 metres apart. In addition the frangible device shall be capable of operating regardless of the direction of impact to the structure.

3.11 Testing

All designs for frangible devices shall be proven by analysis and/or static testing to be capable of withstanding the loads stipulated in sections 3.2, 3.3. Designs which introduce new concepts and/or materials not supported by published engineering data must be verified by static testing.

Static testing of frangible devices shall include but not be limited to; tension, compression, shear, and flexure. Except for impact tests all test procedures shall conform to those of the American Society for Testing and Materials (or equivalent). The tests shall establish the maximum static load capacity of the frangible device consistant with its intended use.

The ability of the frangible device to break at low energy levels when subjected to impact loads shall be demonstrated by dynamic testing.

Testing of frangible devices shall be performed in a manner approved by the contracting authority. The test method may include but not be limited to; drop weight test, swinging pendulum impactor, flywheel impactor, catapult sled, or remote operated or towed aircraft impact. The ultimate goal of impact testing is to determine the energy absorbed by the structure as the impactor passes through it. Testing may be conducted on a single frangible device, however, tests on a complete structure should be carried out to demonstrate windowing effects and wrap around problems. The test specimen shall be oriented so that forces exerted by the test impactor provide the best possible representation of type of forces expected by an aircraft impact.

3.11.1 Static Load Testing

Static load tests on a frangible device shall be used to determine the following properties where applicable:

i) modulus of elasticity
ii) yield and ultimate tensile strength
iii) yield and ultimate shear strength
iv) yield and ultimate bending moment capacity
v) yield and ultimate compressive strength

A minimum of three samples shall be tested for each property or until results vary by less than ± 10%. Tests shall be instrumented to provide a continuous recording of load versus strain up to the yield point. The yield strength of materials which do not exhibit a clearly defined yield point shall be determined by the "offset" method, and shall be the stress where plastic deformation occurs for .2% strain. In all cases the test specimen shall be supported by the testing device in a configuration representing its actual use in the structure.

3.11.2 Impact Tests

Impact tests on frangible devices shall be instrumented to measure:

i) total energy of the impacting device at impact
ii) velocity of the impactor before and after impact
iii) energy absorbed by the frangible device.

The method of obtaining data will depend on the type of impactor. It is desirable to have a continuous record of energy transfer before, during and after impact. The total kinetic energy of the impactor shall be at least twice the amount expected to break the frangible device. The degree of frangibility shall be measured in terms of total energy required to permit the impactor to pass through the structure. This will include the energy to break the frangible device plus the energy to accelerate the mass of the structural member away from the impactor.

3.12 Technical Reports

Design computations shall be presented with sufficient detail to ensure compliance with the static loading requirements of section 3.2 and 3.3 Impact test documentation shall include a description of test type, instrumentation, observations, and results. All numerical data shall be given in S.I. metric units.

PART II

DESIGN REQUIREMENT STUDY FOR FRANGIBLE MLS SUPPORT STRUCTURES

PART II

TABLE OF CONTENTS

SECTION			PAGE NO
1.0		INTRODUCTION	1
	1.1	Background	1
	1.2	Study Requirements	1
	1.3	Report Objective	1
	1.4	Report Organization	1
2.0		SUPPORT STRUCTURE REQUIREMENTS	2
	2.1	Structural Parameters	2
	2.2	Environment	2
	2.2.1	Survival Wind and Ice	2
	2.2.2	Operating Wind and Ice	4
	2.2.3	Deflection	7
	2.3	Jet Blast Loads	8
	2.4	Aircraft Impact Loads	9
	2.5	Materials	10
3.0		FRANGIBILITY CONCEPTS	11
	3.1	General	11
	3.2	Frangible Connections	11
	3.2.1	Fuse Bolts	11
	3.2.2	Special Material Bolts	12
	3.2.3	Tear-Through Fasteners	12
	3.2.4	Tear-Out Sections	12
	3.3	Frangible Members	13
	3.4	Frangible Mechanisms	13
	3.5	Other Concepts	14

SECTION NO.		PAGE NO.
4.0	IMPACT TESTS	15
4.1	Introduction	15
4.2	Test Method	15
4.2.1	Other Test Methods	15
4.3	Description of Test Equipment	16
4.3.1	Support Carriage	16
4.3.2	Pendulum	16
4.3.3	Electronic Instrumentation	16
4.4	Test Results	20
4.4.1	Friction and Windage	20
4.4.2	Impact on Aluminum Bolts	20
4.4.3	Impact on Fiber Glass Member	22
4.4.4	Test Photos	24
4.5	Test Summary	43
5.0	CONCLUSIONS AND RECOMMENDATIONS	44
5.1	Support Structure Design	44
5.1.1	Environment	44
5.1.2	Impact Analysis	44
5.2	Frangibility	44
APPENDIX A	LITERATURE SEARCH OF REFERENCE MATERIAL	
APPENDIX B	LIST OF CONTACTS	
APPENDIX C	STRUCTURAL ANALYSIS OF MLS SUPPORT STRUCTURE AND SIMULATED AZIMUTH ENCLOSURE	
APPENDIX D	INSTALLATION INSTRUCTIONS FOR SUPPORT STRUCTURE (P/N 171323)	
APPENDIX E	INSTALLATION INSTRUCTIONS FOR SIMULATED AZIMUTH ENCLOSURE (P/N 171300)	

List of Illustrations

Figure No.		Page No.
2.1	Wind Map	6
2.2	Ice Map	6
4.1	Impact Test Equipment	17
4.2	Pendulum Motion	18
4.3	Typical Impact Curve	19
4.4	Friction and Windage	25
4.5	Frangible Connection Test Specimen	26
4.6	1/2" Bolt-Shear Connection 2 X 2 X 1/4 Al. Angle	27
4.7	Channel Mass Acceleration	28
4.8	1/2" Bolt - Shear Connection 4 X 2 Al. Channel	29
4.9	1/2" Bolt-Tension Connection 4 X 2 Al. Channel	30
4.10	5/8" Bolt - Shear Connection 4 X 2 Al. Channel	31
4.11	5/8" Bolt - End Connection 4 X 3 X 1/4 Al. Angle	32
4.12	Fiber Glass Angle Test Specimen	34
4.13	Fiber Glass Angle - Without Grooves	35
4.14	Fiber Glass Angle - With .020" Grooves	36
4.15	Fiber Glass Angle - With 1/2" and 1/8" Saw Cuts	37
4.16	Carriage and Pendulum Impactor	39
4.17	Aluminum Angle Before Impact	40
4.18	Aluminum Angle At Impact	41
4.19	Aluminum Angle After Impact	42

List of Tables

Table No.			Page No.
2.1	-	Allowable Deflections	7
2.2		Material Properties	10
4.1		Impact Data For Frangible Connections	33
4.2		Impact Data For Frangible Member	38

1.0 INTRODUCTION

1.1 Background

The existing Instrument Landing System (ILS) currently installed at Canadian airports is to be phased out in favour of the newly developed Microwave Landing System (MLS). Airport environment and local terrain make it necessary to support the MLS antenna above ground level to ensure proper operation. Since the system requirements dictate that the antenna and support structure be located in the vicinity of landing and take-off zones, accidental impact by aircraft becomes a major design consideration.

In order to address this situation Transport Canada has issued Contract T8200-6-6520/01-NG to Andrew Antenna Company Limited (AACL), for provision of an MLS Frangibility Study.

1.2 Study Requirements

The study is intended to fulfill the requirements provided in section 5.1 of the contract document Statement of Requirements for frangible MLS support structures. The study is to consider environmental conditions including survival and operational wind loads plus effects of jet blast and collision forces of impacting aircraft. In addition the study is to reflect upon the results of impact tests conducted on various frangible devices.

1.3 Report Objective

The basic objective of the report is to initiate the development of expertise in the design and analysis of frangible MLS support structures, the ultimate goal of which is to lessen the potential for injury or death to passengers in the event of accidental collision.

1.4 Report Organization

Section 2 outlines the structural requirements for the MLS support structures. Section 3 presents frangibility concepts and basic failure modes to consider. Section 4 describes the impact tests procedure and results obtained. Section 5 presents, the conclusions drawn from the study and recommendations for future efforts.

2.0 SUPPORT STRUCTURE REQUIREMENTS

2.1 Structural Parameters

The essence of frangible structure design is to produce a structure which has low resistance to impact loads yet is capable of both withstanding environmental loads and meeting operational deflection limits. The base of the structure shall be designed to interface with concrete foundations while the top shall provide for interface with the MLS antenna base.

2.2 Environment

The MLS support structure shall be designed to meet the environmental and service condition requirements outlined in Transport Canada document DFS 1000 paragraph 5.3.2 for class 2 outdoor equipment.

2.2.1 Survival Wind and Ice

In order to establish survival wind and ice loading requirements, it is important to consider the type of equipment and the location of its intended use. Frangible MLS support structures are essentially antenna towers which must endure wind and ice loading typical of the Canadian environment. In addition however, the structure should not be designed to such extreme conditions that it becomes immovable in the event of accidental aircraft impact. Therefore the optimum level of wind and ice loading should blend the requirements of the Canadian environment with the requirements of frangibility. The following three specifications address these issues in varying degrees, and have been used in a comparitive analysis to establish the survival wind and ice conditions:

1. Transport Canada Document DFS 1000, General Specification for Procurement of Electronic Equipment.

2. U.S. Federal Aviation Administration Engineering Requirement FAA-ER-530-81-04, Structural/Mechanical Design Requirements For Low Impact Resistance Microwave Landing System Structures (MLS/LIRS).

3. Canadian Standards Association Document CSA S37-M1981, Antenna Towers and Antenna-Supporting Structures.

The survival or non-operating condition in DFS 1000 specifies wind speeds of 160 km/h gusting to 240 km/h with 5.0 cm of radial ice. The FAA survival condition is significantly less severe with a wind speed of 160 km/h including gusts and no ice load. Since wind forces vary with the square of the velocity, the difference in total wind load between the two specifications is around 80%. It becomes obvious that a structure designed to DFS 1000 will have greater strength and conversly be less frangible than one designed to the FAA specification. Exactly how much less frangible is difficult to establish since this would require knowing the relationship between static load capacity and impact strength of the frangible device. The results of a limited test program discussed in section 4 of this report suggest that impact strength can increase by as much as 4 times the rate of static strength. It is therefore extremely important not to over-specify the wind speed and hence compromise frangibility. This is achieved quite effectively in CSA-S37 by establishing a reference wind pressure dependant on location of installation across Canada. Three wind zones are designated to cover certain regions of Canada and are given reference velocity pressures of 450, 600, and 850 Pa. (see fig. 2.1). The design wind pressure is the product of the reference velocity pressure multiplied by the appropriate height factor Ce, gust effect C_g, and shape factor C_p. Assuming typical values of Ce = 1.0, C_p = 1.5 and C_g = 2.0 (as per CSA S37) the design wind velocity for each zone is calculated as follows:

$$p = qC_eC_gC_p \qquad (1)$$

$$v = (p/.5\rho)^{\frac{1}{2}} \qquad (2)$$

where : p = design wind pressure (Pa)

q = reference velocity pressure (Pa)

v = design wind velocity (m/s)

$.5\rho$ = density of air (0.647 kg/m^3)

therefore : CLASS A - $p = 450 \times 1 \times 1.5 \times 2 = 1350$ Pa

$v = (1350/.647)^{\frac{1}{2}} = 45.7$ m/s = 165 km/

CLASS B - $p = 600 \times 1 \times 1.5 \times 2 = 1800$ Pa

$v = (1800/.647)^{\frac{1}{2}} = 52.7$ m/s = 190 km/

CLASS C - $p = 850 \times 1 \times 1.5 \times 2 = 2550$ Pa

$v = (2550/.647)^{\frac{1}{2}} = 62.8$ m/s = 226 km/

These values generally agree with DFS 1000 except they offer the advantage of designing to a lower wind speed in areas where lower wind speeds tend to occur. Ice loading in CSA-S37 is considered in much the same way as wind loading by specifying different thicknesses for different locations across the country as shown in figure 2.2. This too will enable tailoring the design to meet the strength requirements but not reduce frangibility.

In view of this discussion it is recommended that the requirements of CSA S37 be used for wind and ice survival loads. This will help prevent over designing the structure thereby reducing frangibility, yet it will also fulfil the requirements of design for the Canadian environment.

2.2.2 Operating Wind and Ice

Establishing a wind velocity for which the MLS and its support structure remain operational involves many considerations such as; maximum wind speeds for which aircraft would be permitted to land, availability of back-up landing systems should the MLS become non-operational, avoid specifying high operational wind speeds which would compromise frangibility aspects, discussions with other agencies and authorities.
Transport Canada document DFS 1000 specifies an operating wind speed of 160km/h gusting to 175km/h with 5.0 cm of radial ice. The current FAA specification for MLS support structures requires only 130 km/h including gusts, and 1.27 cm of radial ice. Again the difference in total wind load for the two specifications is around 80%.

The Reference velocity pressures in CSA S37 cover a recurrence interval of 30 year, meaning that there is a 1 in 30 chance that the reference velocity pressure will be exceeded in any 1 year. The values are generated from the Supplement to the National Building Code of Canada (NBCC) document on Climatic Information for Building Design in Canada. A 30 year recurrence interval is recommended for survival loads, however it should not be used as a basis for generating operating wind loads. A 10 year recurrence period is better suited for operating conditions, and is also the interval recommended in the NBCC for deflection analysis. Reference velocity pressures for a 10 year recurrence interval for the three wind zones in CSA S37 are given below([1])

CLASS A 380 Pa
CLASS B 520 Pa
CLASS C 760 Pa

(1) Atmospheric Environment Services, Downsview, Ont.

Assuming typical values of C_e = 1.0, C_p = 1.5 and Cg = 2.0 and using equations 1 and 2 of section 2.2.1, the design wind velocity for zones A, B and C would be 150 km/h, 176 km/h and 213 km/h. Ice loading is not expressed in terms of recurrence intervals therefore operating loads should be taken the same as survival ice loads. The relationship between operating wind and ice loads and their corresponding effect on frangible design is similar to the survival loads. Structures can be designed to meet deflection requirement for loads expected at a particular location, but will not be over designed and hence compromise frangibility.

In conclusion, it is recommended that operating wind loads be derived from the requirements of CSA S37 using reference wind velocity pressures for a 10 year recurrence interval. The values of "q" to be used for class A, B and C wind zones should be 380 Pa, 520 Pa and 760 Pa respectively. Ice loading should be applied as per the thickness stated in the ice map.

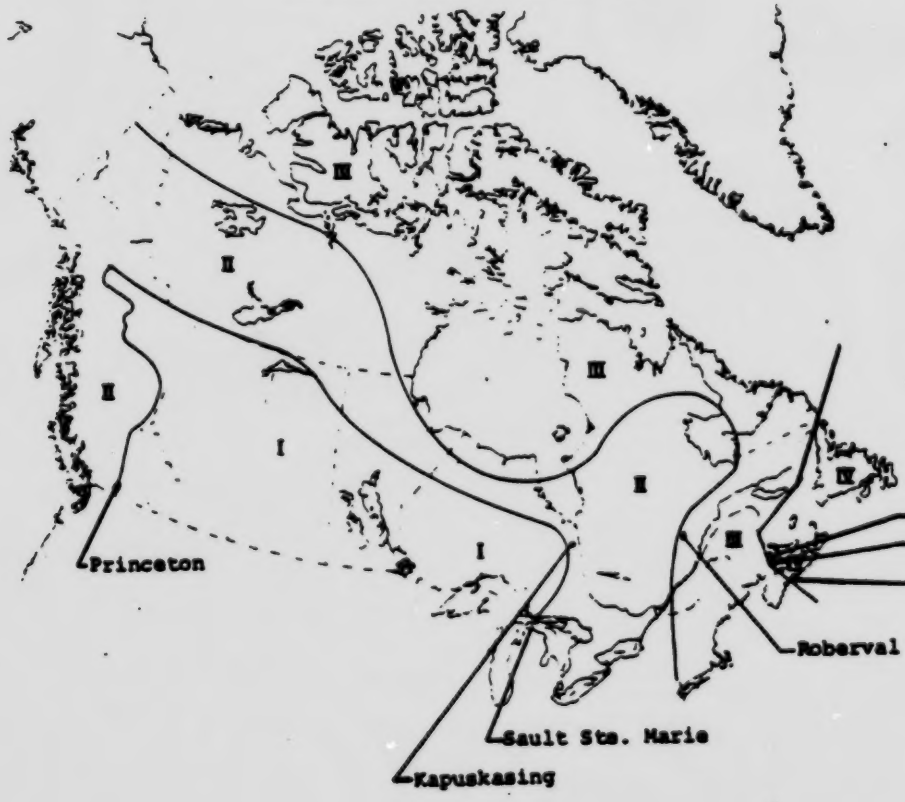
Figure 2.1 Wind Map

Reference
Velocity Pressure
(q)

Survival Wind
Class A 450 Pa
Class B 600 Pa
Class C 850 Pa

Operating Wind
Class A 380 Pa
Class B 520 Pa
Class C 760 Pa

Figure 2.2 Ice Map



Radial Ice
Thickness mm

Class I 10
Class II 25
Class III 40
Class IV 50
Class V Open

2.2.3 Deflection

The MLS support structure shall be sufficiently rigid so as not to exceed the short term deflections under operating wind conditions or the long term deflections due to foundation settlement, as listed in table 2.1. When analysing wind deflections it is important to consider wind directions both face-on and at an oblique angle to the antenna. The front wind will produce the maximum pitch rotation while an oblique wind at an angle around 40 degrees to the face of the antenna will produce the maximum yaw rotation. Guyed structures can be used, however their ineffectiveness in controlling deflections particularly in the yaw direction may make them superfluous. Guyed structures also present a disadvantage in that they tend to broaden the "catch area" of the structure. If guys are to be incorporated in the design, they should contain some form of frangibility and should not be prone to "wrapping around" or otherwise entangling the aircraft. This can be achieved by designing the guys so that there are definite break points along the length and at the ends, also rigid guy poles with frangible connections could be considered.

Table 2.1 Allowable Deflections

DIRECTION	SHORT TERM (DEG)	LONG TERM
PITCH	± 0.1	± 3
YAW	± 0.01	± 3
ROLL	± 0.1	± 3

2.3 Jet Blast Loads

When analysing a blast load there are a number of factors to be considered. The blast will have a specific duration, magnitude, direction, and impulse shape dependent on the source from which it originates.(1) In the case of jet blast the load is applied as an instantaneous impulse which would remain constant for a period of time then gradually decrease to zero.

The structural response to this type of step loading can be related to static deflection by the ratio of impulse duration to natural period of vibration of the structure. Providing the MLS support structure has a relatively low period of vibration (natural frequency around 10 Hz or more) compared to a jet blast of 30 to 60 seconds duration, a dynamic magnification factor (DMF) of 2 could be used. This means that stresses caused by jet blast on the MLS and support structure can be determined by multiplying stresses due to a uniform static load by 2.0.

In terms of wind velocity:

$v_S = (2p/\delta)^{\frac{1}{2}}$

v_S = wind velocity
p = static uniform pressure
δ = air density

a DMF of 2 yields:

$v_B = (2x2p/\delta)^{\frac{1}{2}}$ v_B = equivalent wind velocity for blast loads.

or $v_B = 1.41 v_S$

This means that the velocity of wind to be considered for a blast load should be nominally 1.4 times the velocity of the design wind speed.

The typical location of MLS equipment is 300m beyond the stop end of the runway, with the result that jet blast loads would not exceed the environmental loads. However if site requirements are such that equipment is placed less than 300m from the stop end, the jet blast effects should be evaluated.

The direction of the jet blast will not be horizontal but rather at an angle of 15 degrees to horizontal. The load shall be considered to act alone and not in combination with high winds or ice.

(1) Dynamics of Structures, Clough and Penzien, McGraw-Hill, 1975.

2.4 Aircraft Impact Loads

The nature of the collision forces generated by impacting aircraft will vary significantly depending on a wide varity of factors. The size and mass distfibution, velocity, impact direction, and rigidity of impacting area will vary widely for different aircraft and will influence the support structure on the basis of these parameters. Normally the wing of the aircraft is considered the most vulnerable for impact, however it is possible that landing gear or horizontal rear stablilizers may also strike the tower.

For a given design it is intuitive that a larger aircraft will break through the structure with more ease than a light weight aircraft, and that impact forces should be based on the latter. It would not however be economical if the tower were designed with such high frangibility that it would collapse if the same light weight aircraft merely rolled into it. The resultant loss of thousands of dollars of MLS equipment would in this case be more important than the damage or human risk imparted to the aircraft and passengers. For these reasons it is recommended that the minimum requirements for aircraft impact loads should stem from the resultant forces generated by impact from a light weight aircraft travelling at landing or take-off velocities of around 120 km/h.

The actual magnitude of the collison force is very difficult to establish, involving a time-history type loading and non-linear analysis of the structure. Two commercially available finite element programs capable of analysing these effects are; ANSYS - available from Swanson Analysis Systems, Houston PA., and NASTRAN - available from The MacNeal-Schwendler Corp, Los Angeles, CA. Both programs are capable of modelling material and geometric non-linearities plus time-dependant impact loads. Most major computer service bureaus support these programs and offer them on a lease or purchase basis. They are however very expensive to obtain, approx. $30,000 U.S. per year, and their application is beyond the scope of this study. A more cost-effective solution may be to develop a seperate computer code which focuses on impact analysis and eliminates many of the other features provided by purchased programs. This could be designed to run on a small personal computer instead of a large mainframe required by ANSYS or NASTRAN.

For reasons of time and dollar constraints, this study will demonstrate frangibility by testing and expressing the results in terms of energy losses of break-away mechanisms.

2.5 Materials

The support structure can be fabricated from metallic or non-metallic materials which are not adversly affected by outdoor environmental conditions. Material selected to meet frangibility requirements should be strong, light weight and have a low modulus of toughness. Minimum weight is important to assure that the least amount of energy is expended to accelerate the mass to the velocity of the impacting aircraft. In general terms toughness is defined as the capacity of a material to resist fracture under dynamic loads. The modulus of toughness is the ultimate amount of energy by volume which a material will absorb, and can be determined by taking the area under the stress-strain diagram plotted to failure. Table 2.2 lists some common properties of design materials:

TABLE 2.2 Material Properties

MATERIAL	DENSITY kg/m^3	YIELD STRENGTH MPa	ULTIMATE STRENGTH MPa	ULTIMATE ELONGATION mm/mm	ULTIMATE ENERGY $MN.m/m^3$
MILD STEEL	7850	240	413	.35	114
CAST IRON	7190	41	138	.05	4.5
ALUMINUM 6061-T6	2710	276	310	.12	35
ALUMINUM 2024-T4	2710	275	427	.10	35

Standard commercially available materials will provide the most cost effective design, however non-standard materials such as plastics and fiber glass etc., should also be considered. Non-metalic materials can be specially designed to provide excellent frangibility characteristics, however their structural behaviour may be difficult to analyse because of uncertainty in elastic modulus or material isotropity. In addition it would have to be proven that a proposed plastic or composite material could withstand weathering, solar radiation, temperature fluxtuation etc., typical of an outdoor exposed environment.

3.0 FRANGIBILITY CONCEPTS

3.1 General

The frangible MLS support structure should include concepts such as; low mass members, short member length brittle or low-toughness members and connections, "designed-in" breakaway mechanisms. On impact the structure should achieve a "windowing-effect" whereby the aircraft section may pass through the structure moving the least amount of mass out of the way. The following sections deal with various design concepts each of which has its own advantages and disadvantages. Design may incorporate one or more frangible concepts in order to ensure consequential failure.

3.2 Frangible Connections

In this type of design, frangibility is incorporated in the connection, which can carry the design load but will fracture at impact. The structural member is not designed to break, but rather to transfer the impact force to the connection. A stiff, light weight member will provide efficient load transfer to the connection and minimize energy absorbed from bending and mass acceleration. The connection should break at low energy levels as determined by impact tests. Types of frangible connections include, neck-down or fuse bolts, bolts of special material or alloy, countersunk rivets, that permit the head to tear through the member, gusset plates with tear out sections.

3.2.1 Fuse Bolts

Failure of this type of connection is induced by providing a "stress-raiser" due to removal of material from the bolt shank. One method is to machine a groove to reduce the bolt diameter, or to machine flats in the sides of the bolt making it weaker in a specific direction. Shear strength can be maintained and tensile strength reduced by machining a hole through the bolt diameter but locating it out of the shear plane. Fuse bolts must be carefully installed to insure they are not damaged or overstressed when tightened.

The problem with fuse bolts is that the stress raiser may shorten the fatique life or may tend to propogate under service loads and fail prematurely.

3.2.2 Special Material Bolts

Use of fasteners manufactured from special materials eliminates the need for extensive machining or fabricating, and allows the basic design to consist of conventional cost-effective techniques. The fasteners would be sized to carry the design loads but would be made from material with low impact resistance.

Materials to consider such as steel, aluminum and plastic should be selected based on strength and minimum elongation to failure. Aluminum bolts of alloy 2024-T4 are recommended because they have strength similar to stainless bolts but have only 10% ultimate elongation compared to 50% for stainless. Plastic bolts may have low elongation values, however their strength would have to be established by testing. Since fangibility is based on material selection, it would be extremely important to purchase hardware with guaranteed compliance of physical properties.

3.2.3 Tear-Through Fasteners

Fasteners such as countersunk rivets can be used to sustain shear loads but tear through the base material if the impact force creates a tension load. The hole in the base material would be accurately machined to grip a minimum amount of the area under the head of the fastener. The taper of the countersunk head would also help to initiate the pull-through. This technique relies heavily on manufacturing process and would require extensive quality inspection.

3.2.4 Tear-out Sections

Connecting gusset plates can be designed with notches that will tear-out with the member. In this type of connection the fastener would not break but instead would be used to pull out a section of the gusset plate. Fatique life and manufacturing quality would be the primary design considerations.

3.3 Frangible Members

In this design, the structural member is required to fail and not the end connection. The member should achieve a "segmented" type separation along its length, thereby minimizing the amount of mass acceleration and reducing the potential of a wrap-around effect. Material selection is not likely to be metallic, but rather something more brittle such as plastic, fiberglass or other non-metals. The main advantage with frangible members is that impact forces do not have to be carried back to the connection in order to fail the section. This means that energy will not be absorbed by bending the member as may be the case in frangible connection design. The disadvantage is that special non-metalic materials require extensive testing to establish properties to be used for deflection analysis of the structure. The analysis should also be confirmed by doing full scale load tests on the structure. Non-metals must also contain ultra-violet inhibitors to protect against the environment.

Plastic extrusions or fiber glass molded sections are available in angle or tube shapes. Angle shapes can be bolted together more easily than tubes which usually require flanges or special couplings for assembly. Members can also be specially fabricated to incorporate built-in break points. This is done by bonding one material to another at points along the length of the member. The bond line then becomes the fracture initiation point in the member.

3.4 Frangible Mechanisms

Frangibility can be incorporated to the support structure by means which do not require the connection or the member to actually break. Instead failure occurs through a mechanism which slips or folds away on impact and removes the structural integrity of the support. A frangible mechanism can be designed to withstand high wind loads but remain very sensitive to impact loads. They tend to be directional in strength, ie. carry high tension and bending but very low shear.

Friction joints used as frangible mechanisms can supply high strength normal to the sliding surface but will slip when the force is applied parallel to the sliding surface. In an MLS support structure, impact forces will be predominantly horizontal. Friction joints should be designed so that the slip plane is horizontal and complete failure will occur if impacted in any direction in that plane. This can be achieved by using flange type couplings on the ends of tower legs, or interconnected tubes which slide apart on impact.

"Swing-away" support members can also be used as frangible mechanisms. These would be incorporated to the structure to provide stability but if broken away on impact would leave the structure unstable and allow it to collapse. This type of design however, does not lend itself to achieving the desired "windowing-effect" and may require large amounts of mass to be moved out of the way before failure.

Any design using frangible mechanisms would have to ensure that no slippage or change in shape would occur from cyclic loading. For example in a design using interconnected tubes vortex shedding on a round tube could cause it to wiggle part way or completely out of its counterpart.

3.5 Other Concepts

The category of other concepts includes the less conventional types of frangible design. The concepts may work in theory however, their application to MLS support structures may be somewhat impractical.

Exploding bolts, or retracting/electromagnetic connections could be used to handle wind loads, but activate just before impact to provide frangibility. One of the main problems with these devices is that they require a trip mechanism to activate them. A sensor or fold down pole would need to be placed infront and behind the structure whereby an impacting aircraft would hit it first, activating the release of the bolts or magnetic connection, then continue on to hit the structure. If all systems worked properly, the tower would absorb only the energy needed to accelerate the fragments out of the way, however if the mechanism did not work, damage to the aircraft could be substantial.

4.0 IMPACT TESTS

4.1 Introduction

Linear stress analysis techniques are not applicable to frangible design, which requires complex time-history impact loading and non-linear material properties. Frangibility data is therefore obtained from impact testing of individual components of the support structure. The primary objective in testing is to measure the amount of energy required to break the frangible device. Other information to be obtained from testing should include, velocity of impactor at contact and peak force at impact.

This section describes equipment used for impact testing of various frangible devices, and the results obtained from the tests

4.2 Test Method

The method selected for testing frangible devices, for this report uses a pendulum type impactor shown in figure 4.1. A weighted arm is released from a position of known potential energy and impacts the test specimen at the bottom of its swing. The impactor breaks the specimen and passes through to a point where it stops on the upswing. The difference in potential energy between the start and end positions of the impactor represents the energy absorbed by the frangible device.

4.2.1 Other Test Methods

The pendulum type impactor was selected for this study primarily because of its simplicity in mechanics and instrumentation. Other methods which may be considered include; drop weight tests, flywheel impactor, catapult sled, or actual aircraft impact by remote operation. The cost can range from a few dollars to several thousands, and therefore has a major influence on the type of test program. The best method is probably the catapult sled incorporating aircraft components as the impacting device. This would provide an accurate representation of mass, velocity, and stiffness of impact area, which would not be the case for pendulum, drop weight or flywheel tests. In addition it would provide a better illustration of impact damage than obtainable from a remote operated aircraft impact. In a remote operated aircraft impact, it is likely that more damage would be caused to the test aircraft from the crash after impact than from the actual impact with the tower.

4.3 Description of Test Equipment

4.3.1 Support Carriage

The pendulum impactor and the frangible test specimen are mounted on a support carriage shown in figure 4.1. The portion of the carriage to which the pendulum is attached can be raised or lowered by hydraulic cylinders to permit loading of the impactor. Steel brackets bolted to a cross member of the carriage hold the test specimen in place, and can be used to vary the distance between the point of impact and the frangible device.

4.3.2 Pendulum

Impact to the test specimen is provided by a triangular shaped pendulum with 254 mm x 254 mm x 12.7 mm steel plates attached at the end. The impact force is applied by a 38 mm dia. solid steel bar fastened through the centre of the plates. Total weight of the system is 1152 N and the center of gravity is just above the top of the plates 1.91 m away from the pivot point. Motion of the pendulum during impact testing is shown in figure 4.2. When raised into position the C.G. of the pendulum is 90 deg. from its position at impact. The product of the height at this point and the weight, is the potential energy, 2200 N.m. When released, the pendulum will swing down to the impact point, converting all potential energy to kinetic energy. Velocity of the pendulum at impact is found from the following energy equations

$$P.E. = mgh$$

$$K.E. = 1/2mv^2$$

$$mgh = 1/2mv^2$$

$$v = (2gh)^{\frac{1}{2}}$$

where:

- m = mass
- g = acceleration of gravity
- v = velocity
- h = height above impact point

Neglecting friction and windage the velocity at impact would be 6.1 m/s.

After impact with the test specimen, the pendulum will swing up to a height which is measured to give the loss in potential energy.

FIGURE 4.1
IMPACT TEST EQUIPMENT

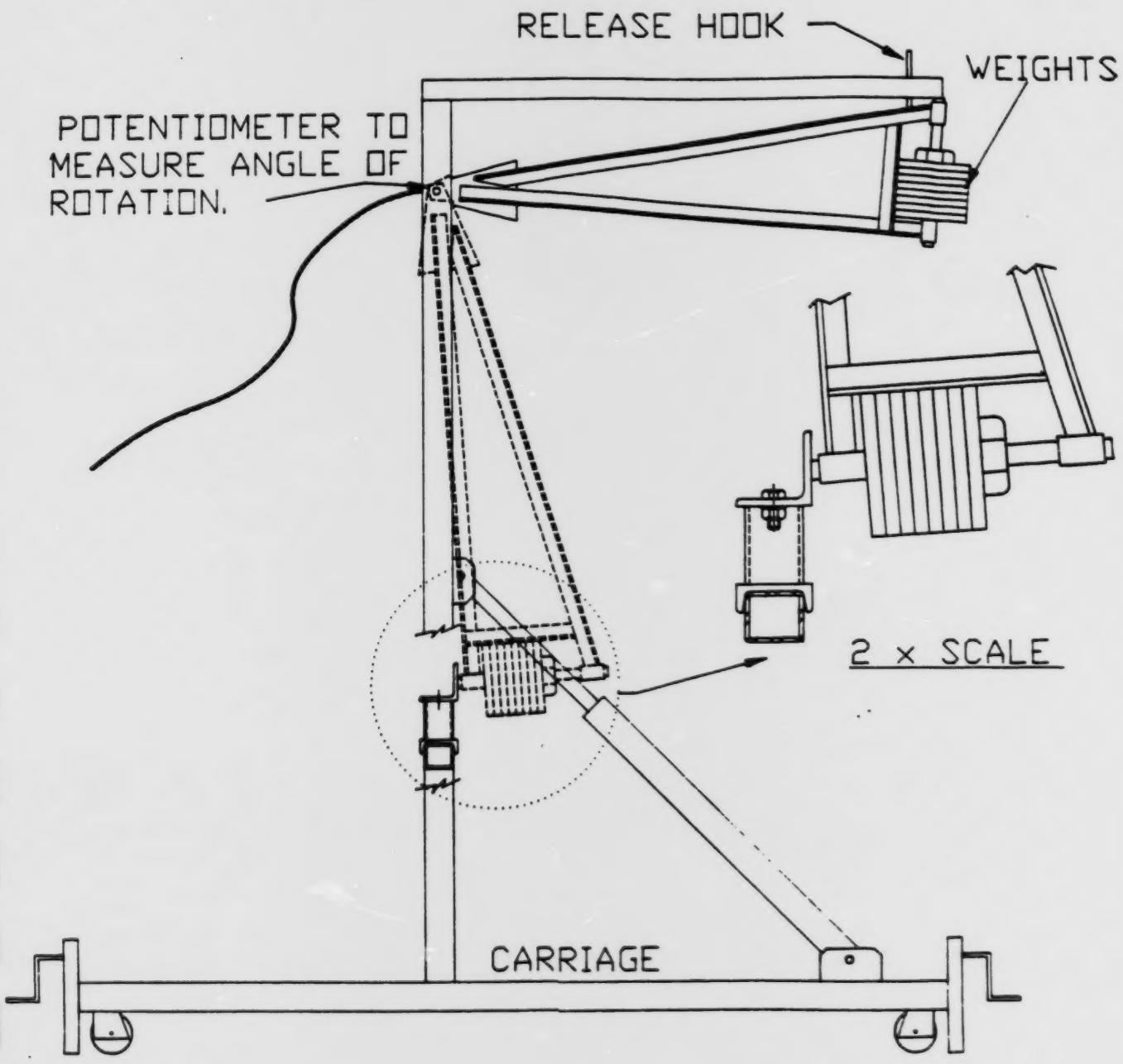
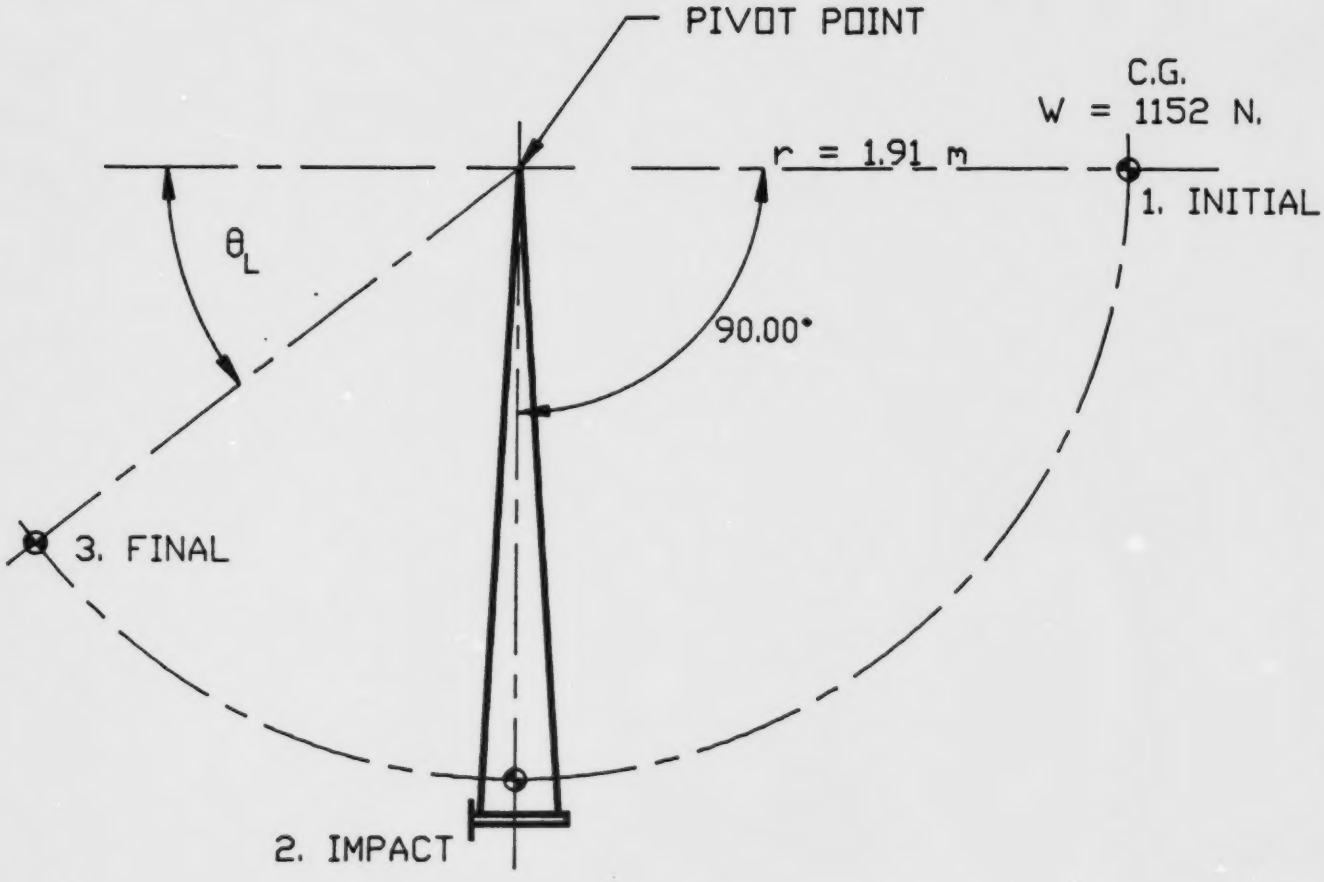


FIGURE 4.2
PENDULUM MOTION



POSITION 1. P.E. = 1152 x 1.91 = 2200 N.m.

POSITION 2. K.E. = 2200 N.m.

VELOCITY = $\sqrt{2 \times 9.81 \times 1.91}$ = 6.1 m/sec

POSITION 3. ENERGY LOST $E_L = Wr(\sin)\ \theta_L$

$E_L = 2200\ (\sin)\ \theta_L$

S.O. or E.P. No.	
Type No.	
Desc.	
Name, Date	

ANDREW

90 deg.

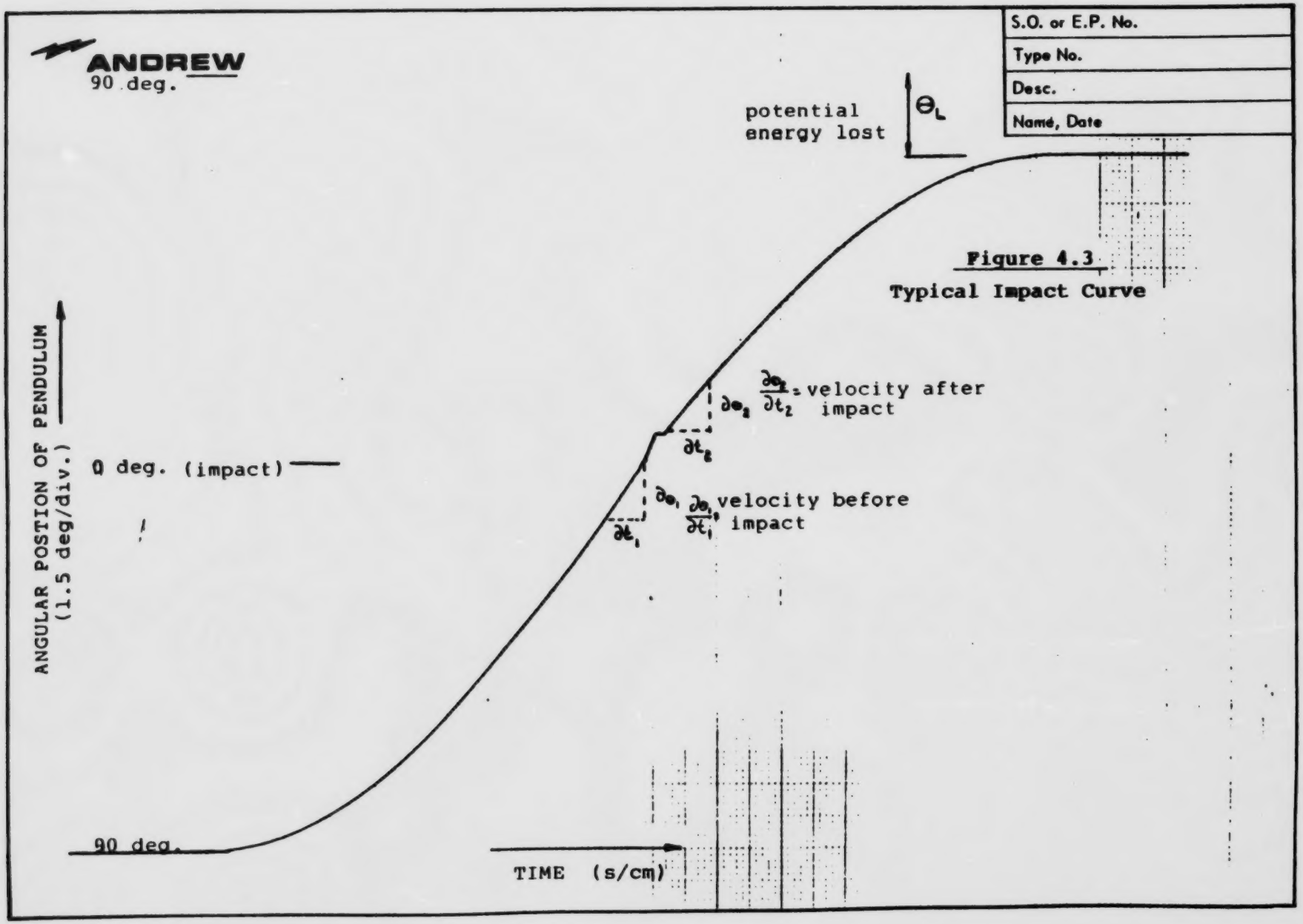


Figure 4.3

Typical Impact Curve

4.3.3 Electronic Instrumentation

The test equipment is instrumented to provide energy and velocity data from the impactor. A linear potentiometer mounted at the pivot point measures the angular rotation of the pendulum, and sends voltage output to a Hewlett Packard 7015B chart recorder. The chart recorder plots an impact curve showing angular position of the pendulum versus time (see figure 4.3). The distance between the top straight line portion of the curve and the 90 deg line represents the angle θ_L and gives the total energy lost. The slope of the curve before and after impact represents the velocity which can be equated to kinetic energy.

4.4 Test Results

4.4.1 Friction and Windage

The first tests carried out were to determine the friction and windage losses associated with the impactor design. Friction losses come from the motion of the steel plate at the apex of the pendulum on the steel pivot pin. A lubricant was applied to the surface of the pin to minimize the losses. Testing was done inside the AACL engineering lab, thereby eliminating losses from external cross winds and reducing windage losses to only the drag on the pendulum.

Friction and windage losses shown by the impact curve in figure 4.4 and table 4.1, have a consistent value of $\theta_f = 4.5^o$ or 172 N.m of energy. This value will be subtracted from the total energy loss on subsequent tests to remove friction energy from the impact energy.

4.4.2 Impact on Aluminum Bolts

Aluminum bolts were tested in various sizes and configurations in order to represent frangible connection design. Bolt sizes tested were 1/2"-13 X 1 1/2" and 5/8"-11 X 1 1/2 in aluminum 2024- T4 alloy. Impact curves are provided in figures 4.6 to 4.11 and summarized in table 4.1. The main goal in testing bolted connections was to determine the energy required to break a 1/2" or 5/8" bolt in a shear or tension connection.

The first test used a 2X2X1/4 6061-T6 aluminum angle as the member with a 1/2" aluminum bolt at one end and a 5/8" steel pivot bolt at the other end (fig. 4.5a). Bolts were spaced 915mm centre-to-centre and used in a shear connection with impact applied in the centre of the angle. Impact curves on two test pieces are shown in figure 4.6.

On impact it was observed that the angle bent 2" in the centre absorbing energy from the impactor then sheared the 1/2" bolt and swung out of the way of the impactor. In both tests the angle maintained a 2" permanent bend but no signs of tearing or cracking, and the bolts sheared at the point where the nut faced against the angle. In terms of potential energy the total absorbed by impact was 720 N.m and 773 N.m. Kinetic energy absorbed is also given in table 4.1 however these values are not as accurate as those for potential energy. This is because kinetic energy includes a velocity squared term, and any error in reading velocity from the curves gets squared in computing kinetic energy, (typical accuracy ± 15%).

The next set of tests were run to separate the amount of energy absorbed by the member from that used to shear the bolt. The test set-up was the same except the angle member was replaced with a stiff channel section (fig. 4.5b.). The 4"X 2" channel section has 3 times the mass of the angle and was considered significant enough to necessitate measuring the energy required to accelerate the mass. This was done by impacting the section restrained by only the 5/8 pivot bolt and allowing it to swing freely about that point. Impact curves in figures 4.7 show the energy to accelerate the mass to be 187 N.m. The 1/2" aluminum bolts were then installed and three tests were run with results shown in figure 4.8. In all cases the channel did not develope any permanent bend, and the energy to break the fastener was found to be relatively low (average value. of 178 N.m). This would indicate that in the first tests using aluminum angle, the energy absorbed by the angle was about 570 N.m or about 3 times the energy to break the bolt. The optimum design then would use a member stiff enough to prevent energy absorbtion from bending but light enough to minimize energy lost to mass acceleration.

The same set-up with the stiff channel was used to measure the fracture energy of the 1/2" bolt in a tension connection (fig. 4.5c). Prior to testing it was expected that the tension connection would absorb more energy than the shear connection, however not more than the total 2200 N.m available from the impactor. The result was that on impact the tension connection did not break, and the impactor merely bounced off the member as shown by the ripple in the impact curve on figure 4.9. This indicates that the energy required to break a tension connection would be more than 4 times that to break the same bolt in a shear connection.

The next step was to test the 5/8" aluminum bolt in a shear connection. If it is assumed that fracture energy increases by the square of the diameter (as elastic strength does) then, based on shear tests of 1/2" bolts, the 5/8 bolt should shear at less than 700 N.m of total potential energy. However, when tested in the same shear connection as the 1/2" bolt, the 5/8 bolt did not break, (figure 4.10). As a result it can be concluded that impact strength increases at a much greater rate then the ratio of the bolt areas.

The last type of frangible connection tested, used a 5/8" aluminum bolt in an end connection producing shear and tension forces (fig. 4.5d). The test piece was made from a 600 mm long 4X3X1/4 aluminum angle with a 3/4" thick base plate welded to the end. The assembly was fastened to the mounting bracket on the impactor, with a single 5/8 aluminum bolt through the base plate and positioned so that impact was 300 mm from the base. Three tests were run on this type of connection and impact curves are provided in figure 4.11. The combined effects of shear and tension induced from overturning caused failure in the bolt for all 3 cases. The base plate had some bending but the weld and the angle had no damage. This type of connection may be applicable to design of tower legs for the support structure.

4.4.3 Impact on Fiberglass Member

In order to evaluate the frangible member design concept, various impact tests were conducted on samples manufactured from glass fiber polyester reinforced material. The selected structural shape was 3 X 3 X 1/4 angle weighing about 2/3 of the equivalent aluminum section. The material surface has a "mat like" finish while the inner core has continuous layers of glass fibers running parallel to the length of the member.

Each of the three test pieces was fastened to the impactor mounting brackets with a single 5/8" steel bolt at each end. The first test section (fig. 4.12a) was a plain section with no grooves or discontinuities, the second (fig. 4.12b) had .020" grooves milled into the outer face near the ends and in the centre of the angle, the third section (fig. 4.12c) had saw cuts 1/2" deep in from the edge and 1/8" deep in the heel, at the ends and centre of the angle. Impact curves for the tests are provided in figures 4.13 to 4.15 and summarized in table 4.2.

Impact of the first test piece with no stress-raisers, produced a fracture energy of 925 N.m. The angle was observed to bend and crack along the inside heel then tear-out from one end at the bolt attachment. The tear-out released the bending force in the angle before a permanent bend set in, allowing the angle to snap back to it's original straight section. A piece of material the same width of bolt was pulled out of the end of the angle in the same direction as the glass fibers. The conclusion from this test was that the edge distance for the mounting bolt controlled the energy absorbed from impact.

The second impact test was on the angle containing three sets of .020" deep grooves. Inorder to reduce the potential for tear-out, the edge distance for the mounting bolts was increased from 25.4 mm to 50.8 mm. The impact curve in figure 4.13 shows an energy level of 1240 N.m an increase of 30% from the first test. Examination of the member showed separation of the glass fibers started at the centre groove due to tensile bending stresses. The entire bottom flange and part of the vertical flange fractured then the section tore away from the end bolt. The increased edge distance caused the flange to split with the grain of the fibers, instead of actually tearing out a section of material as the angle pulled away from the bolt. It is likely that the fracture energy could be reduced by increasing the groove depth or by machining the groove on both faces of the angle.

The third test was conducted on the angle section containing saw cuts in the flanges and heel. The impact curve in figure 4.15 shows 1118 N.m absorbed by fracture. This member was the only one which fractured completly through the cross-section. Fracture was initiated at the centre saw cuts in the edges and heel, and caused longitudinal separation of the glass fibers across the full section of the angle. Each half of the member remained fastened to the end bolts, with no tear-out at either end.

This test produced the best illustration of the "windowing-effect" of frangible design. The frangible member concept, of not breaking the end connection but rather fracturing the member at pre-designed break points along its length, may produce the most effective design.

4.4.4 Test Photos

Photographs of the impact test equipment and typical impact of an aluminum angle are provided in figures 4.16 to 4.19. Figure 4.16 shows the carriage and pendulum. Figure 4.17 shows the angle before impact, figure 4.18 shows it immediately after impact, bending and swinging away from the pendulum after shearing the aluminum bolt. Figure 4.19 shows the damage to the angle resulting from the impact.

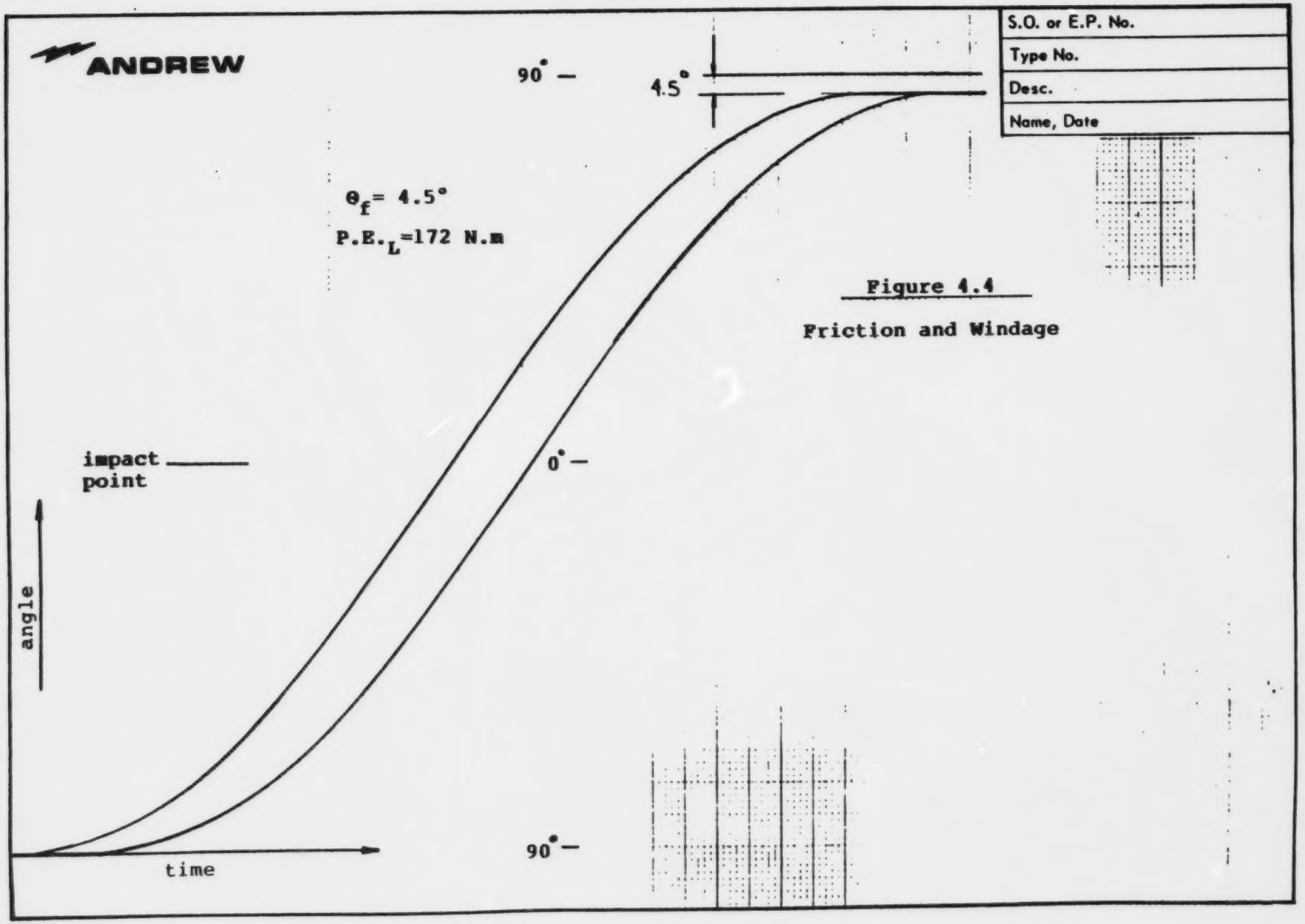
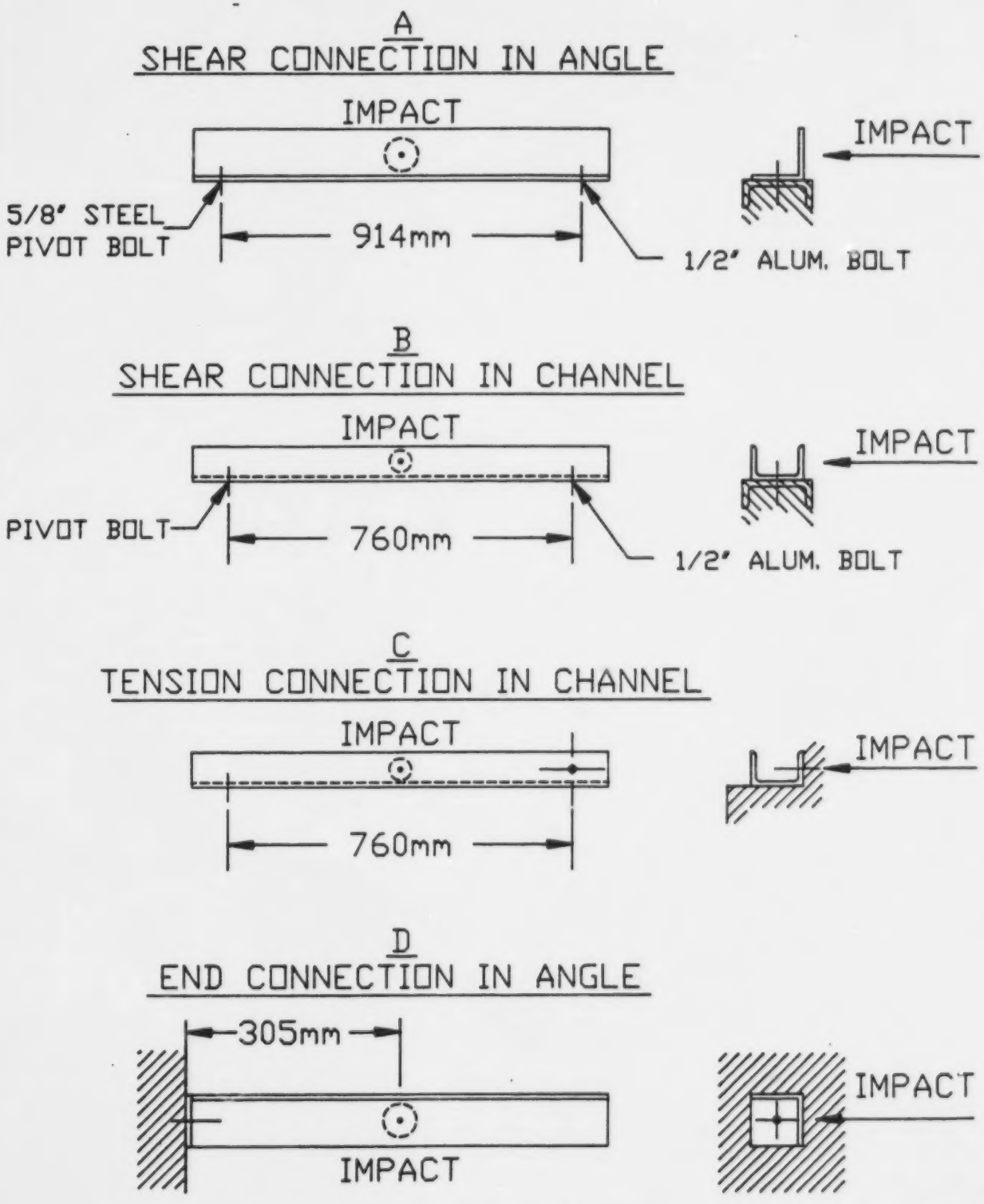


Figure 4.4

Friction and Windage

Figure 4.5

FRANGIBLE CONNECTION TEST SPECIMENS



ANDREW

S.O. or E.P. No.	
Type No.	
Desc.	
Name, Date	

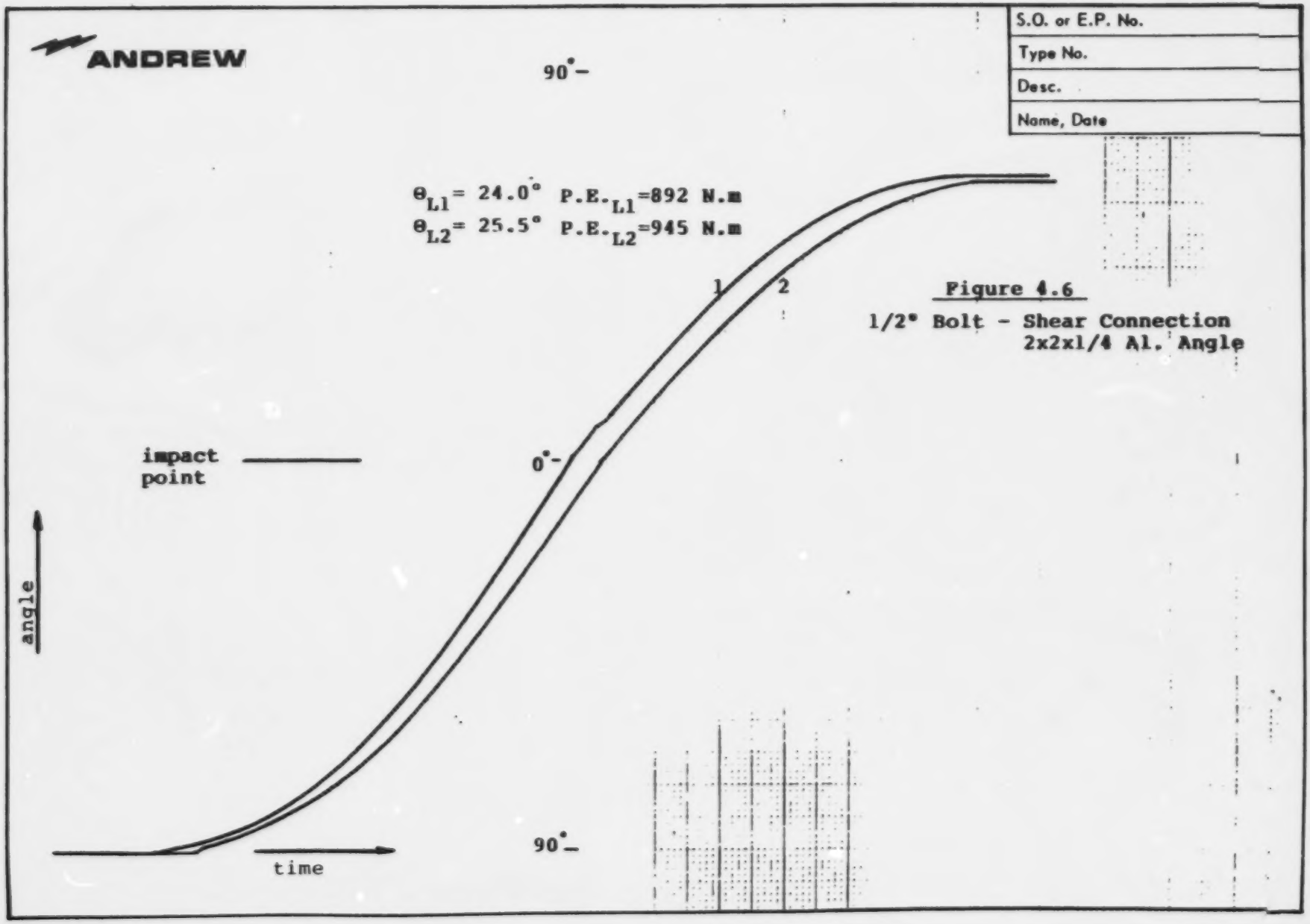


Figure 4.6

1/2" Bolt - Shear Connection
2x2x1/4 Al. Angle

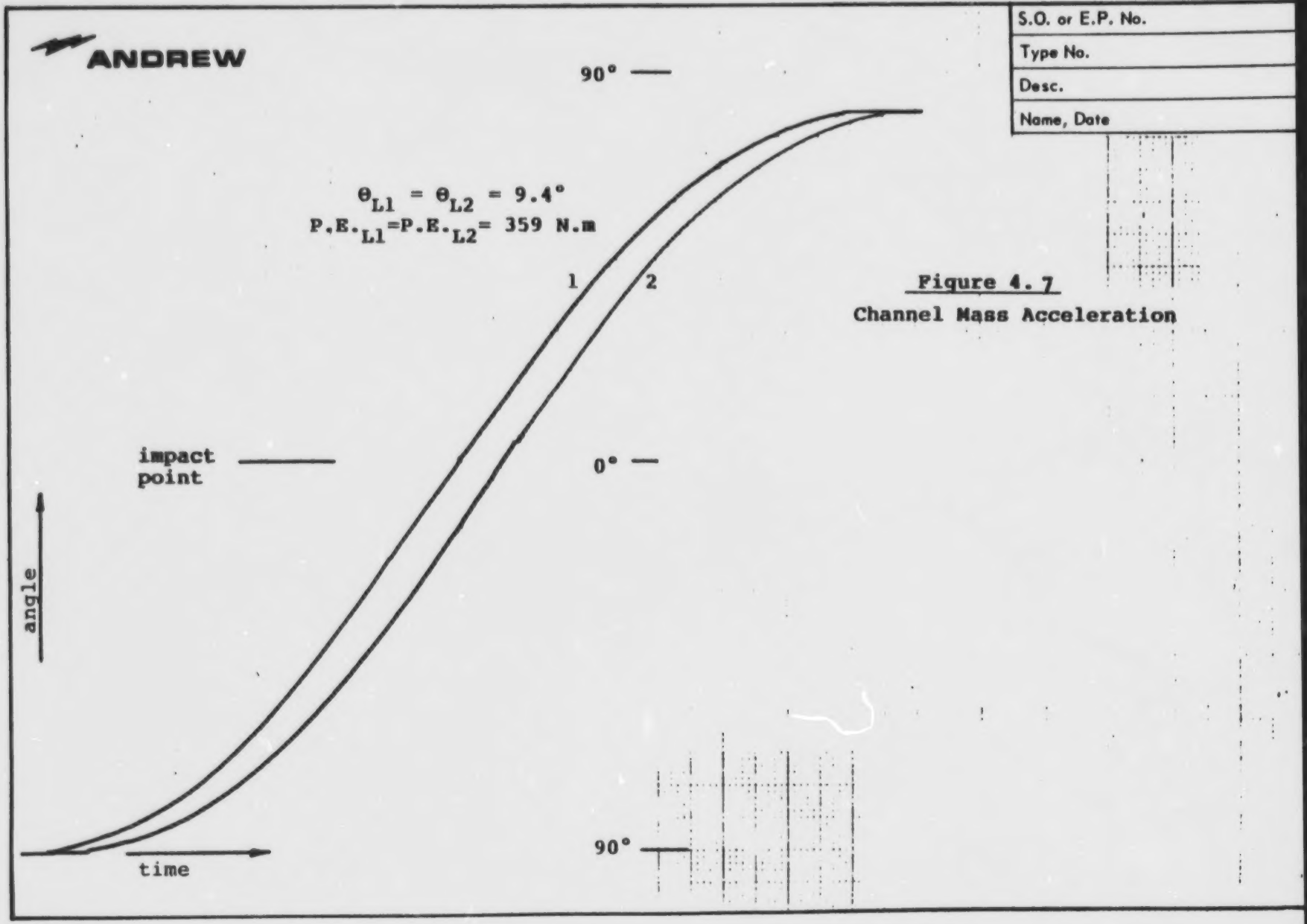


Figure 4.7
Channel Mass Acceleration

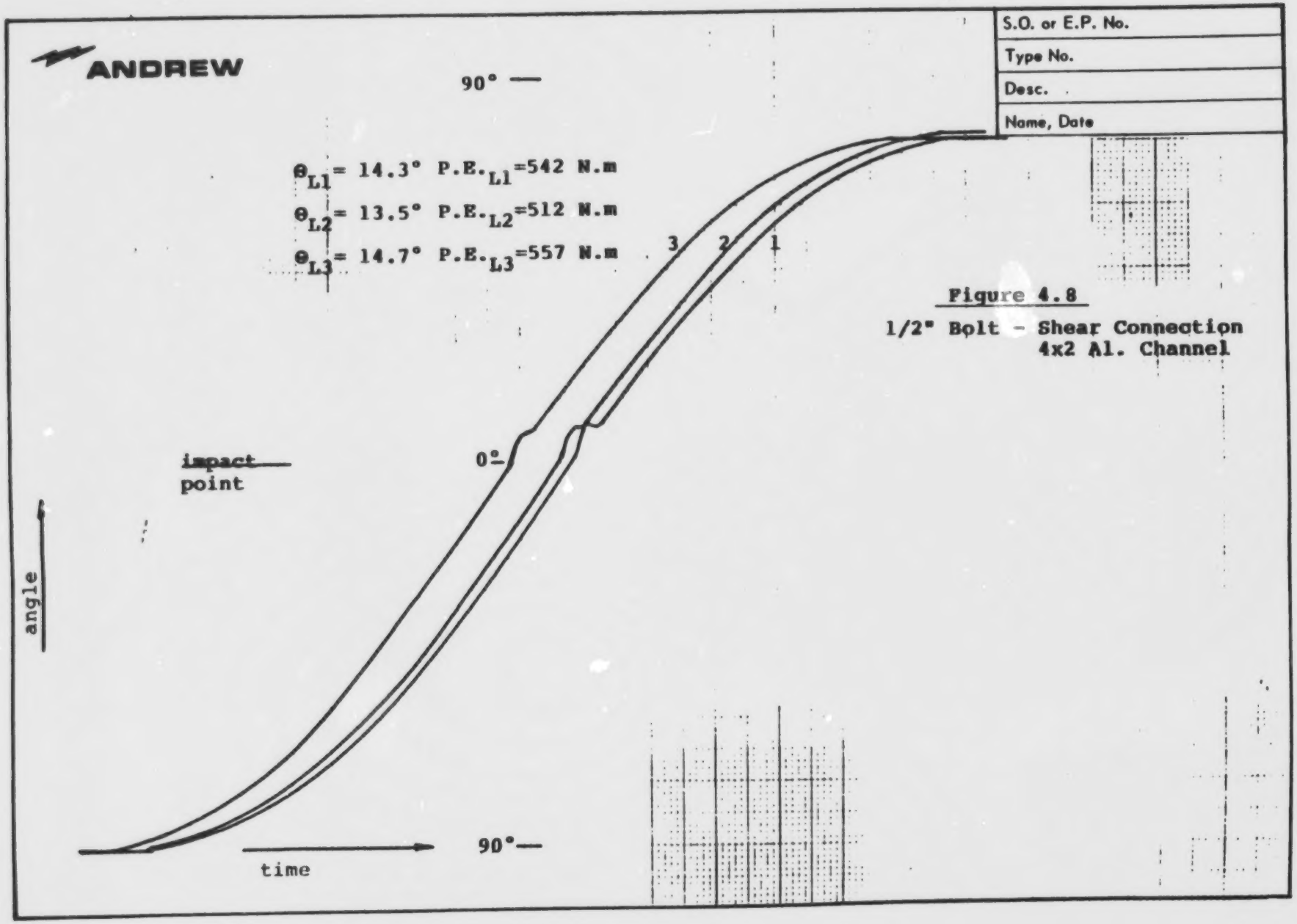


Figure 4.8

1/2" Bolt - Shear Connection
4x2 Al. Channel

ANDREW

S.O. or E.P. No.	
Type No.	
Desc.	
Name, Date	

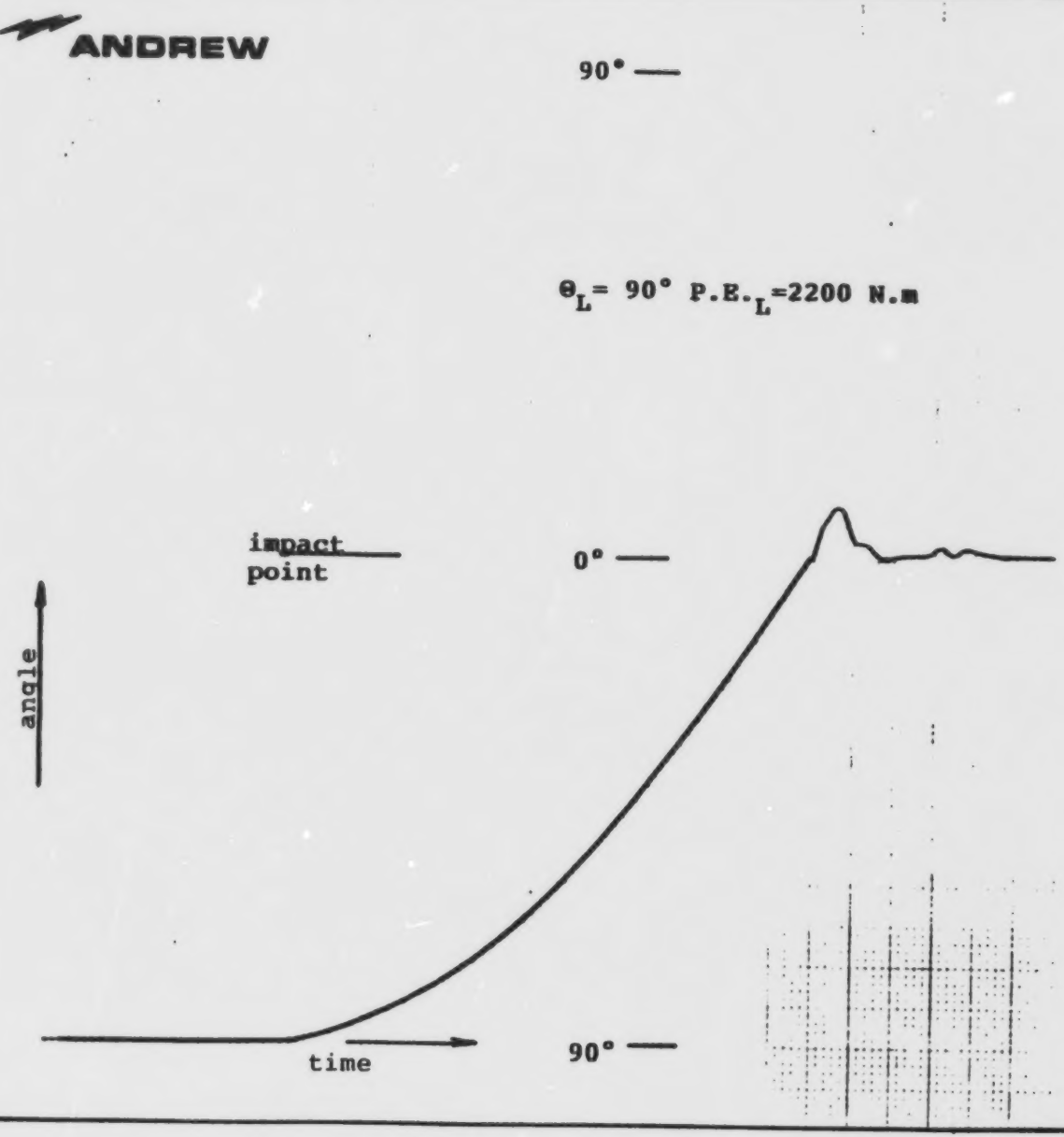


Figure 4.9

1/2" Bolt - Tension Connection
4x2 Al. Channel

ANDREW

S.O. or E.P. No.
Type No.
Desc.
Name, Date

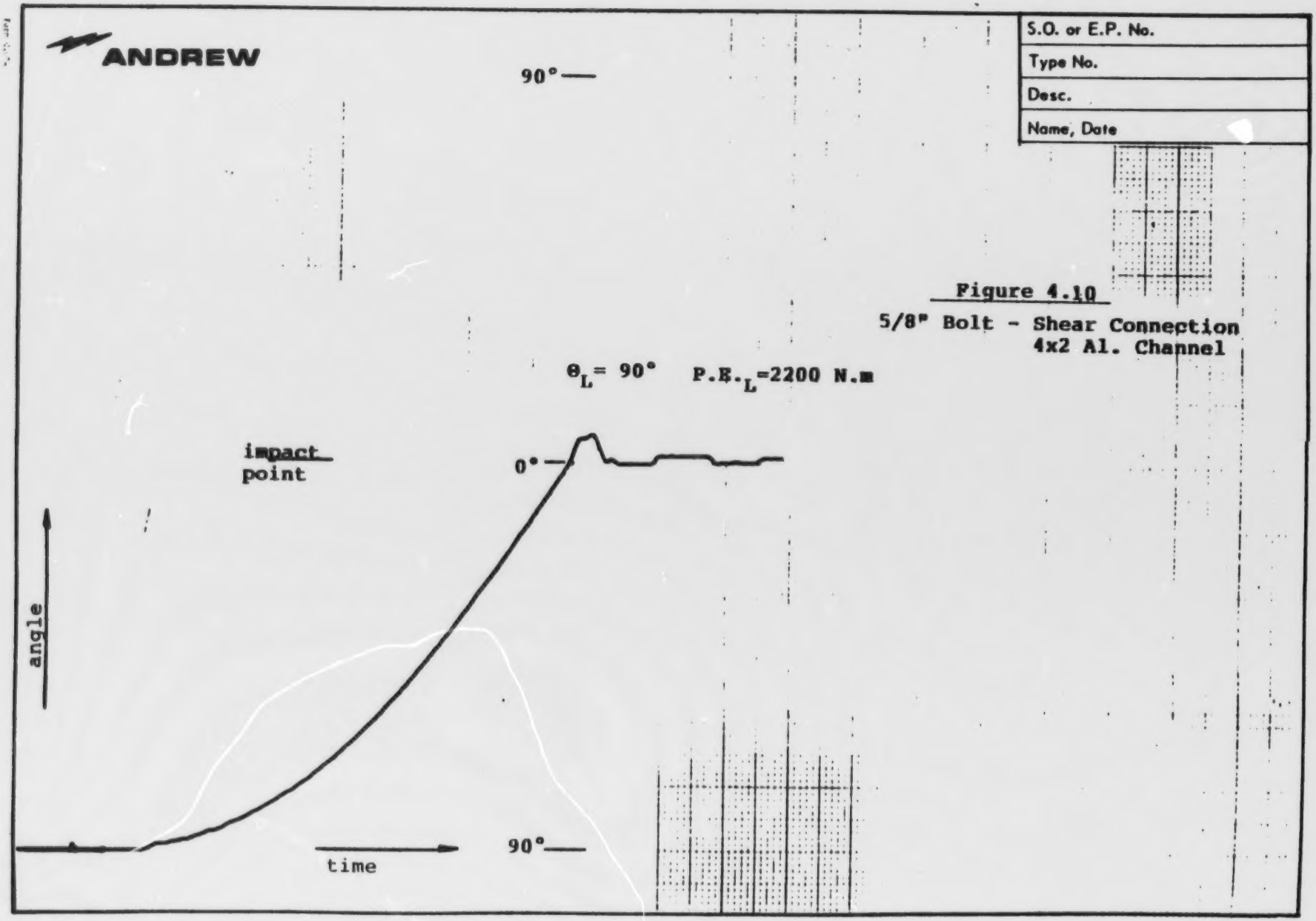


Figure 4.10

5/8" Bolt - Shear Connection
4x2 Al. Channel

ANDREW

S.O. or E.P. No.
Type No.
Desc.
Name, Date

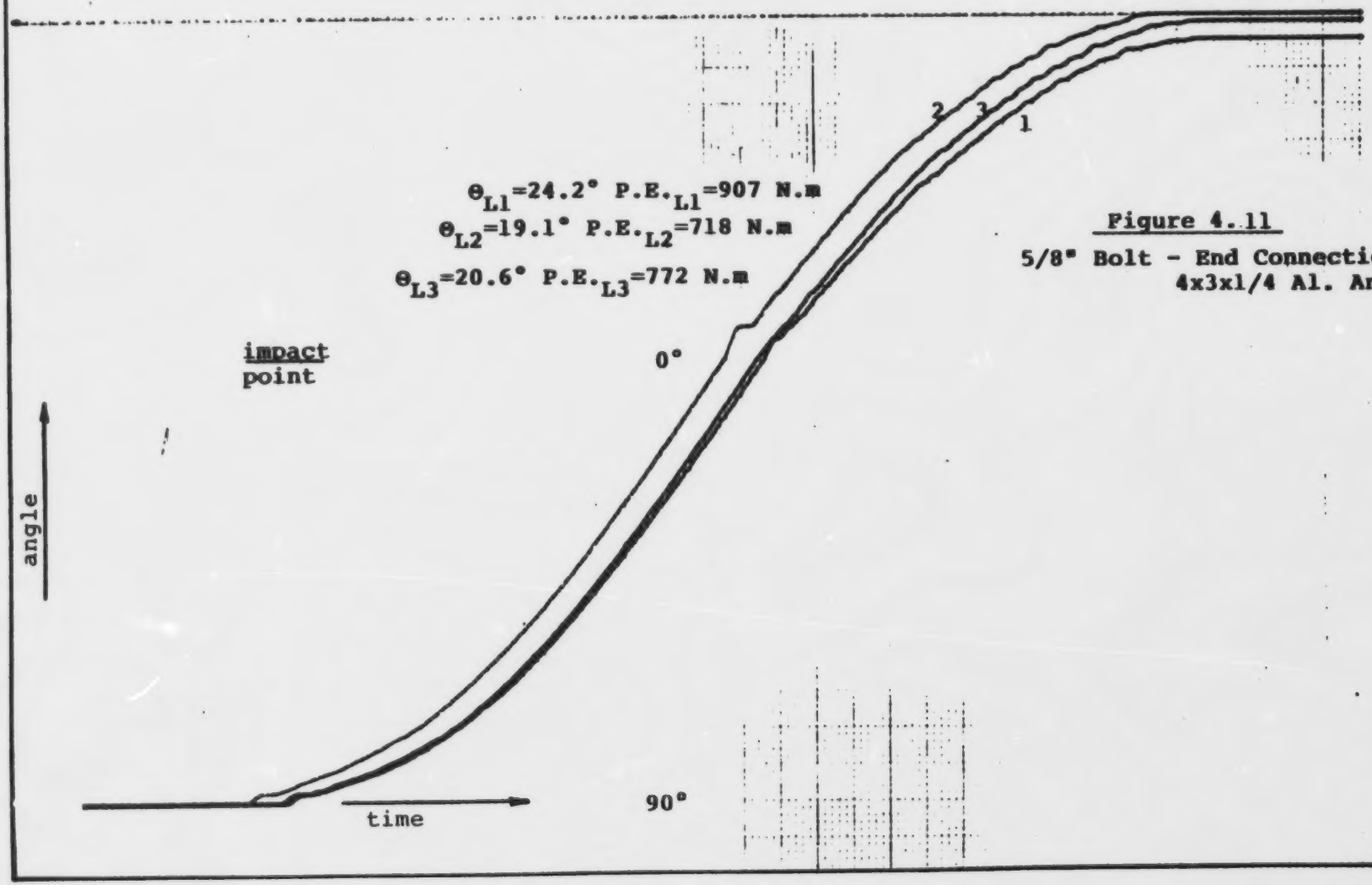


Figure 4.11

5/8" Bolt - End Connection
4x3x1/4 Al. Angle

Table 4.1

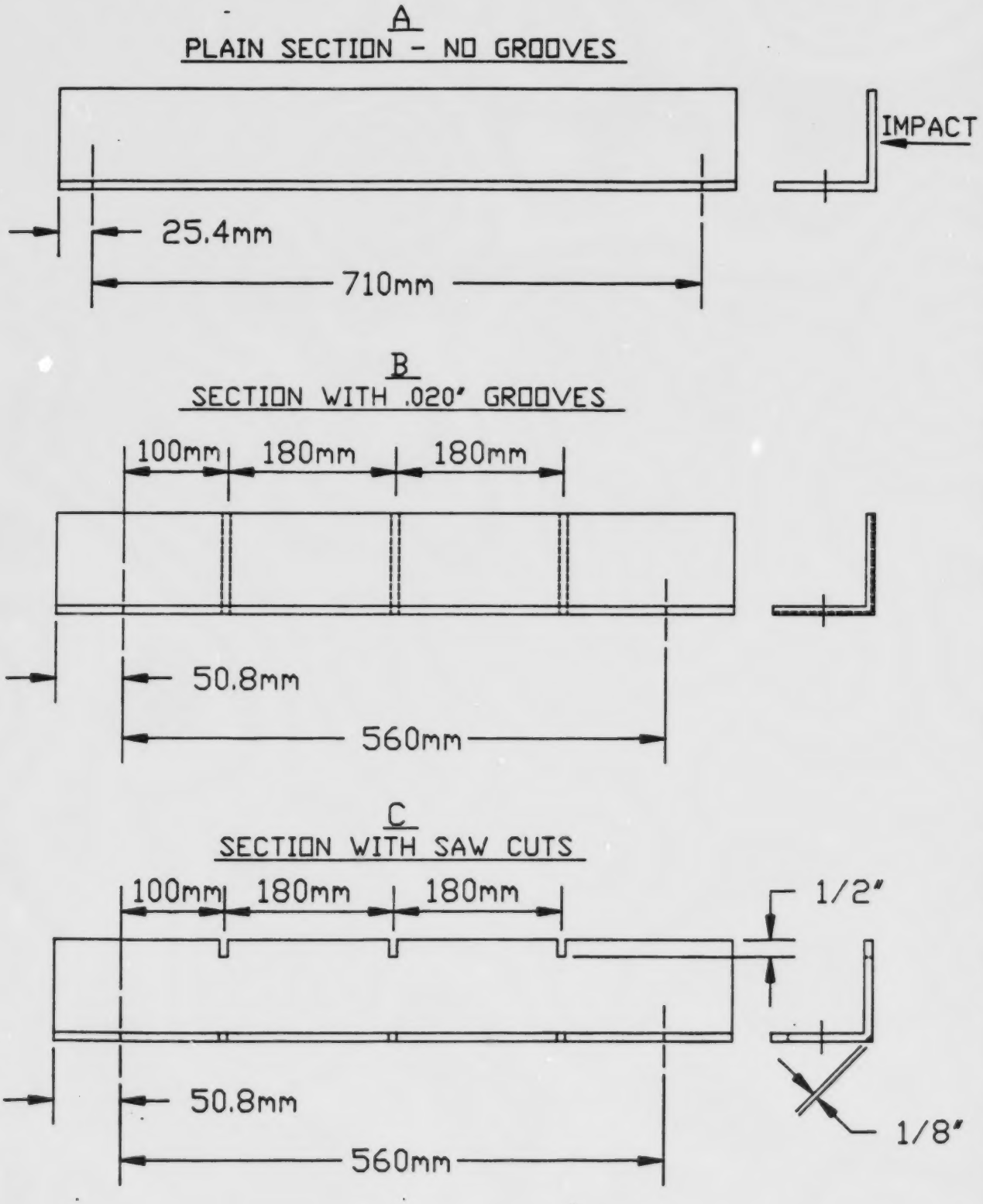
Impact Data For Frangible Connection

Test Description	KINETIC ENERGY K.E		POTENTIAL ENERGY P.E.			
	V_2 m/s	$K.E._I$ N/m	θ_L Deg	$P.E._L$ N.m	$P.E._I$ N.m	$P.E._F$ N.m
Friction and Windage(Fig.4.4)	5.64	0	4.5	172	0	0
1/2" Bolt-Shear Connection 2X2X1/4 angle						
1.	4.33	767	24	892	720	N/A
Fig.4.6 2.	4.11	872	25.5	945	773	N/A
Channel Mass Accel						
1.	5.20	271	9.4	359	187	0
Fig.4.7 2.	5.24	252	9.4	359	187	0
1/2" Bolt-Shear Connection 4X2 Channel						
Fig 4.8 1.	4.85	487	14.3	542	370	183
2.	4.91	452	13.5	512	340	153
3.	5.00	399	14.7	557	385	198
5/8"Bolt-End Connection 4X3X1/4 Angle						
Fig. 4.11 1.	4.21	827	24.4	907	735	548
2.	4.88	469	19.1	718	546	359
3.	4.57	639	20.6	772	600	413

V_1 = velocity of pendulum before impact (constant 5.64 m/s)
V_2 = velocity of pendulum after impact
$K.E_I$ = kinetic energy lost due to impact
θ_L = angle below 90° on the upswing of the pendulum
$P.E._L$ = total potential energy lost
$P.E._I$ = potential energy lost due to impact
P.E. (TOTAL - FRICTON)
$P.E._F$ = potential energy lost or abosrbed by the frangible connection.
P.E. (TOTAL - FRICTION - MASS ACCELERATION)

Figure 4.12

FIBER GLASS ANGLE TEST SPECIMEN



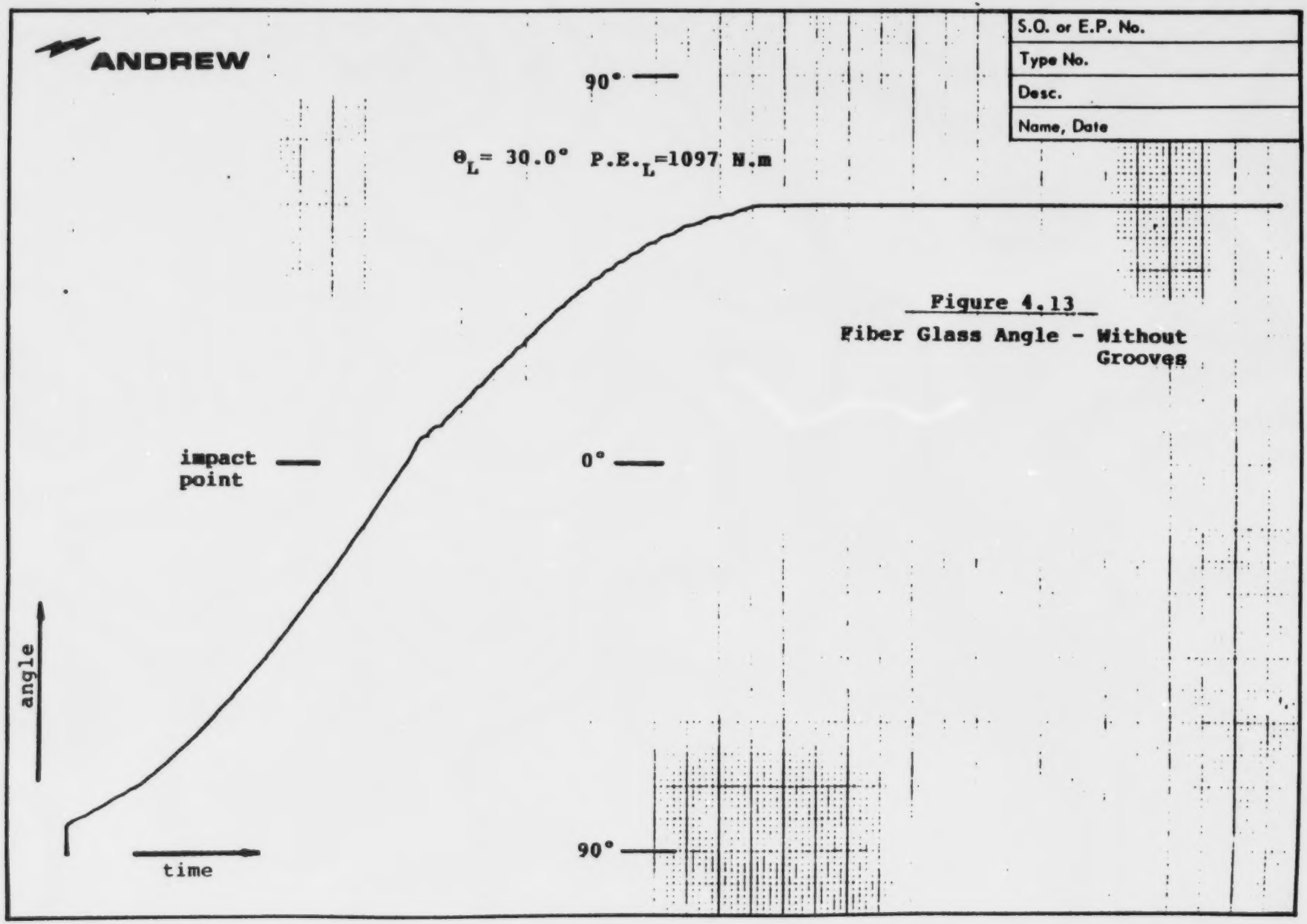


Figure 4.13

Fiber Glass Angle - Without Grooves

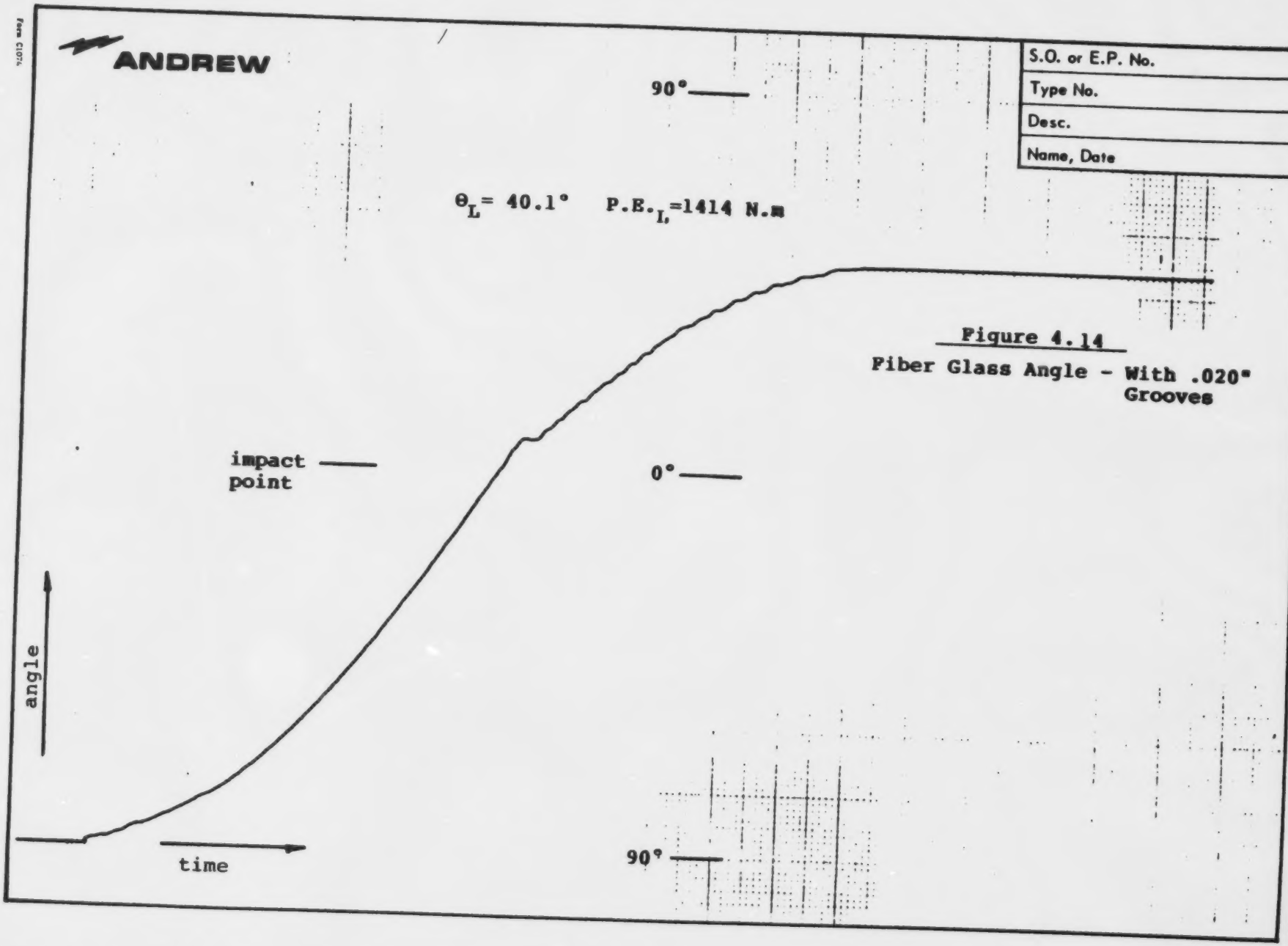


Figure 4.14
Fiber Glass Angle - With .020" Grooves

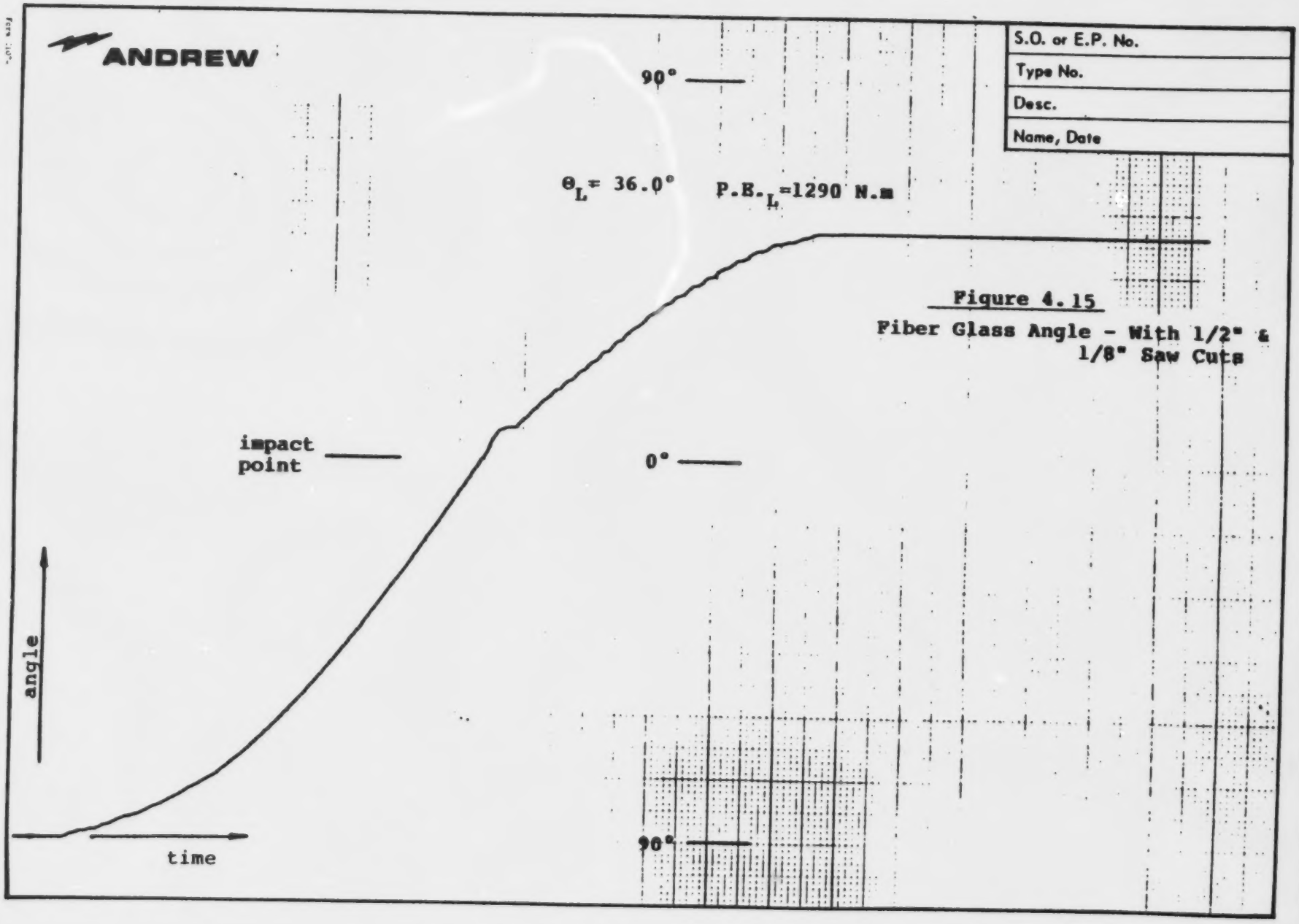


Figure 4.15

Fiber Glass Angle - With 1/2" & 1/8" Saw Cuts

Table 4.2

Impact Data For Frangible Member

Test Description	KINETIC ENERGY K.E		POTENTIAL ENERGY P.E.		
	V_2 m/s	K.E.$_I$ N/m	θ_L Deg	P.E.$_L$ N.m	P.E.$_I$ N.m
Fibre Glass Angle-Without Grooves Fig. 4.13	3.84	1001	30.0	1097	925
Fibre Glass Angle-With .020" Grooves Fig. 4.14	3.20	1266	40.1	1414	1240
Fibre Glass Angle With 1/2" & 1/8" Saw Cuts Fig. 4.15	3.32	1218	36	1290	1118

- variables same as Table 4.1

Figure 4.16 Carriage and Pendulum Impactor

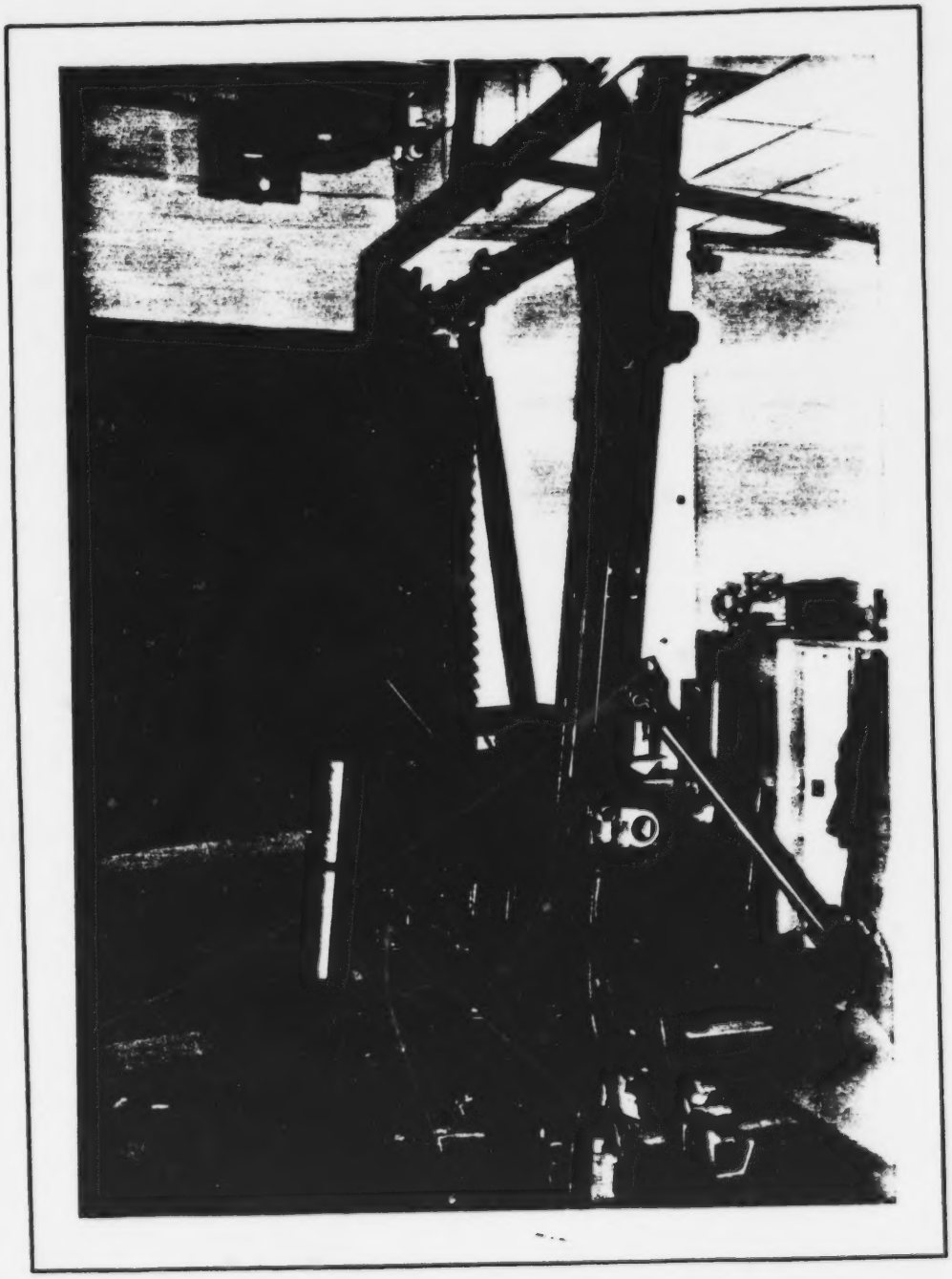


Figure 4.17 Aluminum Angle Before Impact

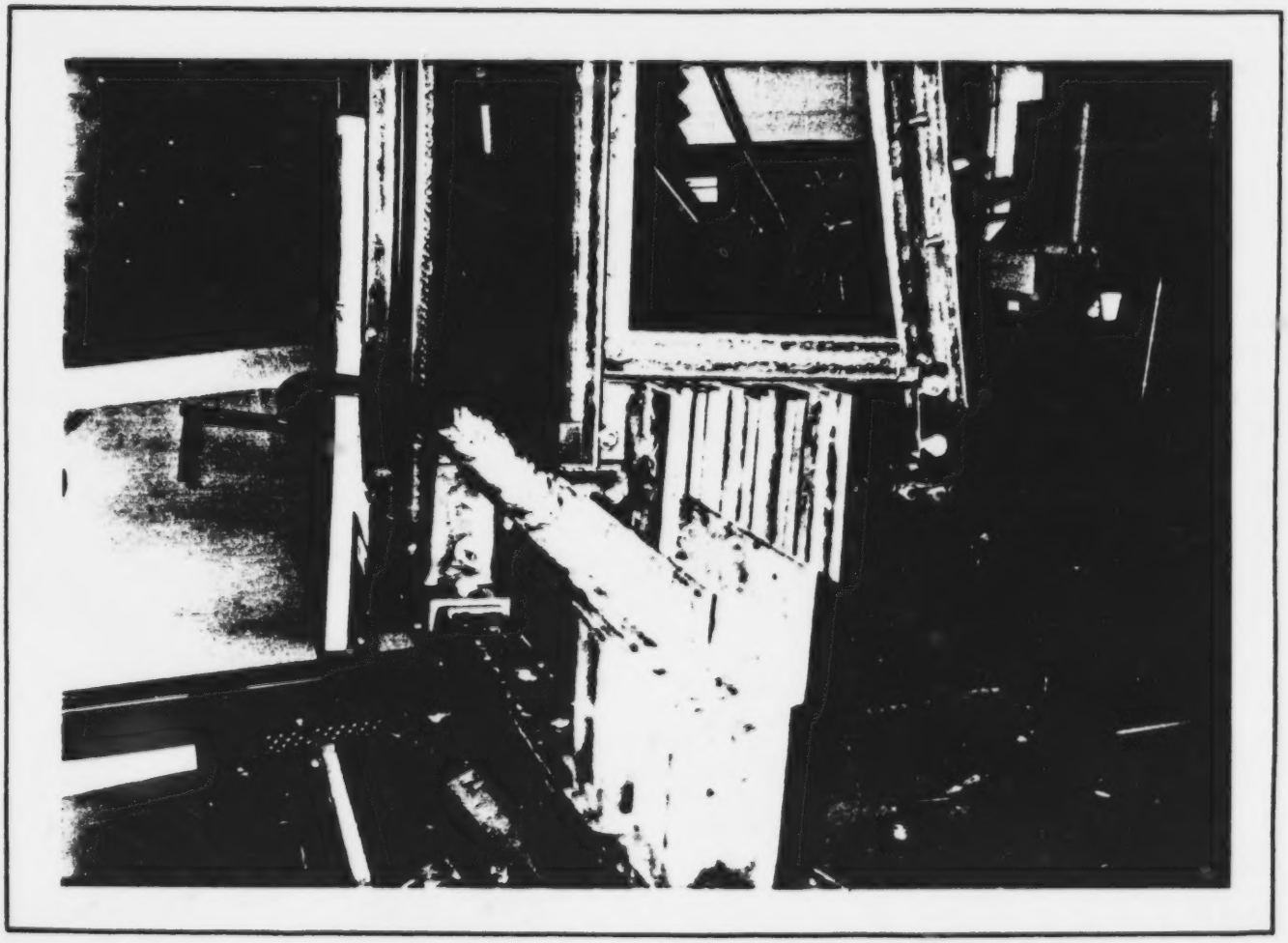


Figure 4.18 Aluminum Angle At Impact

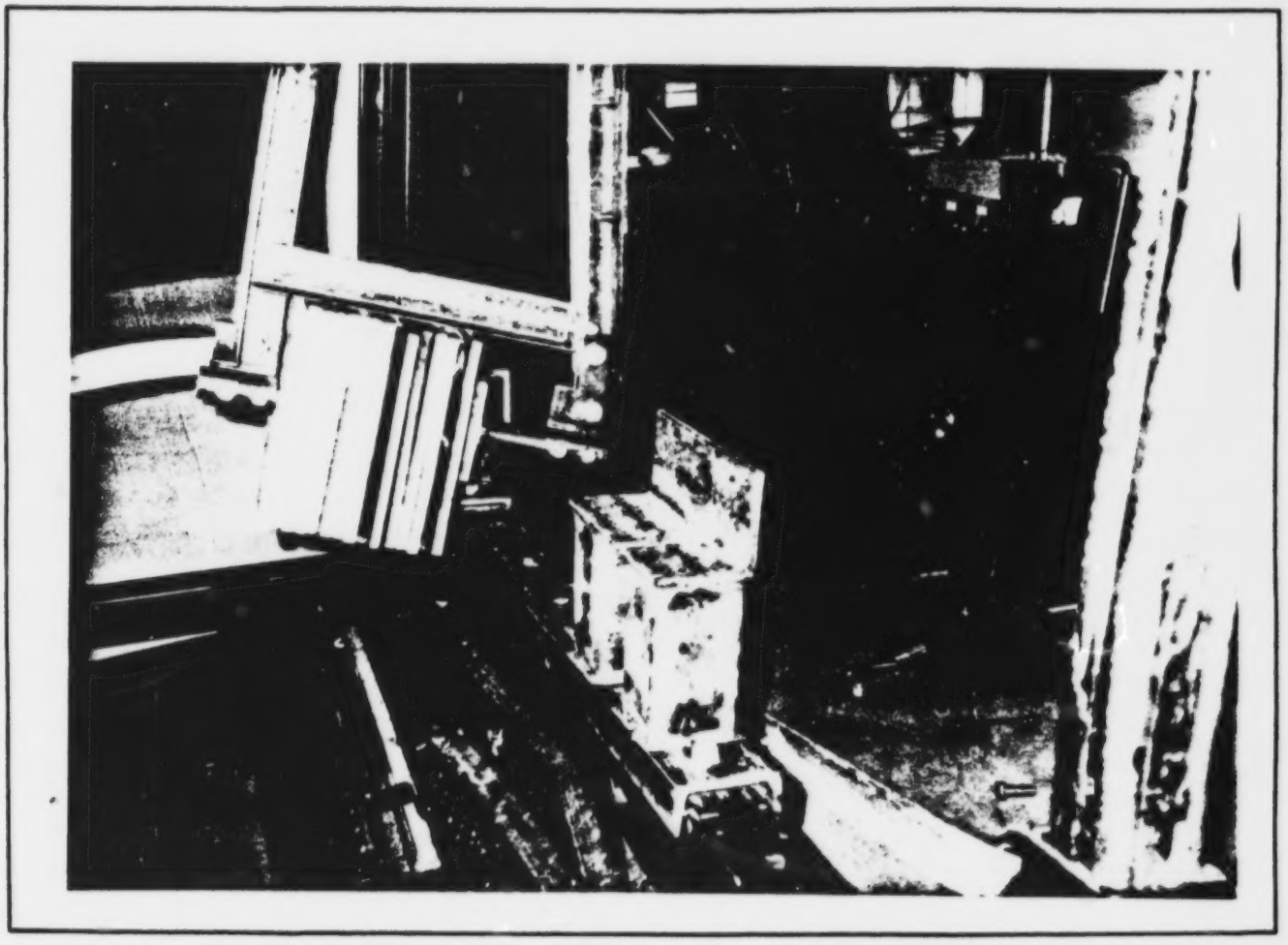
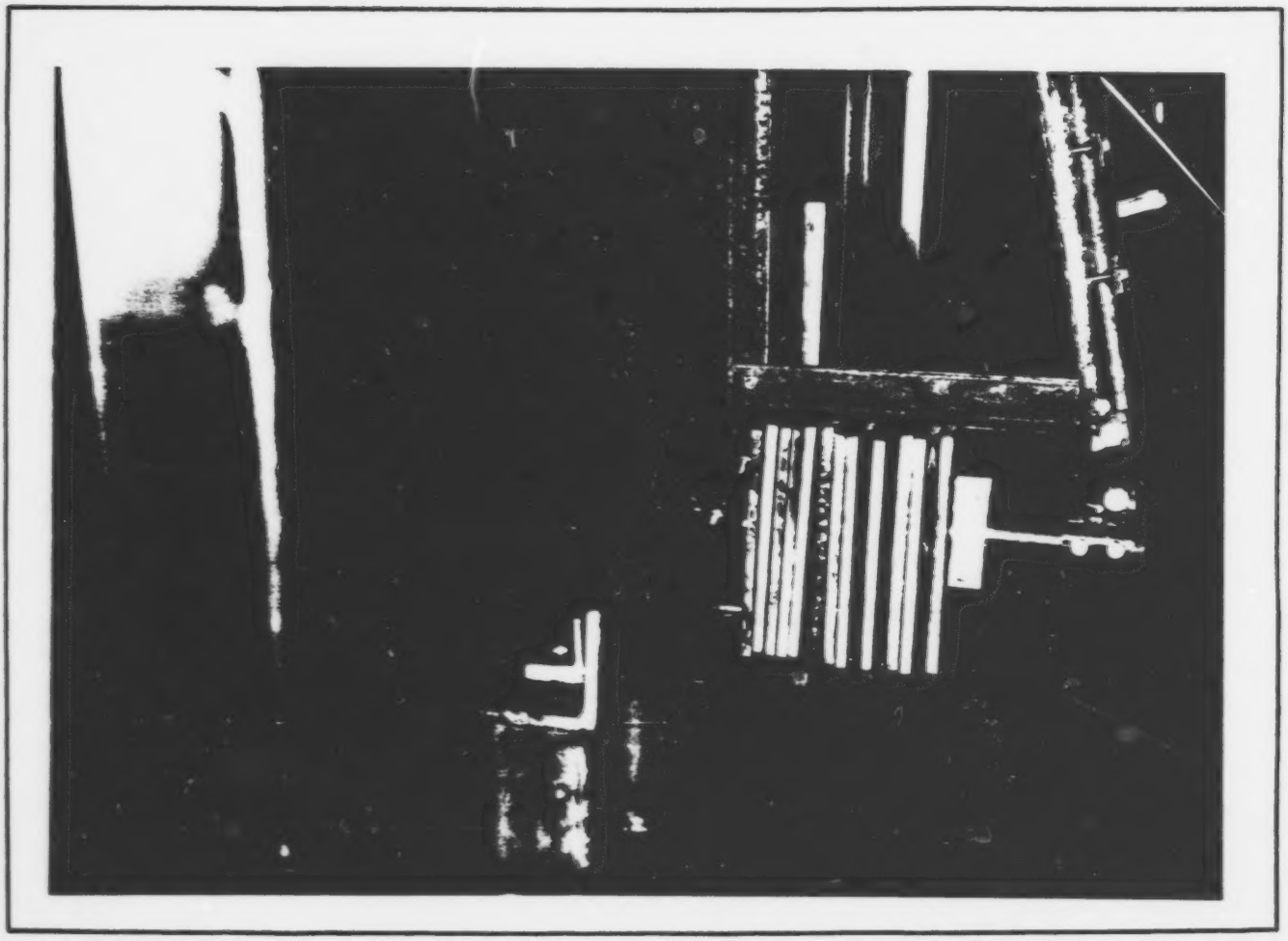


Figure 4.19 Aluminum Angle After Impact



4.5 Test Summary

The two concepts considered for the frangibility test program were; frangible connection design, and frangible member design.

Testing of frangible connections focused on aluminum bolts in shear, tension and combined shear and tension failure. Results show that failure of the connection will depend on how the member transfers energy from the point of impact to the connection. A member with insufficient stiffness will absorb more energy from plastic deformation than required to fracture the bolt. A stiff member which does not plasticly deform is likely to have increased mass and will absorb energy from mass acceleration. The appropriate design would balance stiffness and weight to provide efficient energy transfer to the connection, and minimize energy absorbtion by the member.

Two main observations made regarding frangible fasteners were; energy required to break a fastener in a tension connection is much higher than a shear connection, and impact strength for different bolt sizes increases at a much greater rate than the ratio of their cross sectional area. Designing a connection so that the fastener receives the combined effect of shear and tension resulting from an overturning moment will greatly reduce the total energy absorbtion.

Testing of a frangible member design was limited to fiber glass material in angle form, utilizing various stress raiser (or grooves) configurations. The material selected was light weight and exhibited brittle failure on impact. Typical fracture showed longitudinal separation of the glass fibers initiating at the stress raiser and spreading across the section. Tests indicate that it is possible to control the energy absorbtion by changing the size or geometry of the notch. In addition it would be possible to achieve segmented "windowing-effect" frangibility by building in stress raisers along the length of the member.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The following sections present conclusions and recommendations drawn from the study, pertaining to both the basic design requirements for MLS support structures, and the requirements for frangibility.

5.1 Support Structure Design

5.1.1 Environment

Environmental conditions provided in Transport Canada document DFS 1000 specify wind speeds and ice loading for outdoor exposed equipment. Comparison of this document with applicable CSA and FAA specifications indicates that both the operating and survival wind velocities of DFS 1000 are high. Designing the support structure to meet excessive wind velocities will undoubtedly compromise frangibility. A similar comparison of radial ice thickness also shows DFS 1000 to be the most severe. The concern here is not so much weight effects but rather the increased drag developed on ice covered lattice type structures. It is recommended that if environmental conditions of DFS 1000 are to be met, then an exception should be made for frangible structures to allow lower wind velocity and less ice thickness. Loads should also be established on the basis of site location, and not set at one value for the entire country. For these reasons it is recommended that the survival loads be computed as per the requirements of CSA S37 section 3.2 The operating loads should also be derived from CSA S37 except the reference velocity pressure should be for a 10 year recurrence interval.

5.1.2 Impact Analysis

Commercially available finite element programs exist which can be used to analyse time dependant impact loads, and non-linear material response, characteristic of frangible structure design. Further research should be done into the suitability of the various codes for frangible analysis with consideration given to developing a separate program incorporating the specific requirements from each. Computer analysis should be correlated with test results, starting with a simple model and progressing to a full structural analysis.

5.2 Frangibility

A limited test program was carried out on frangible connection and frangible member design concepts. The conclusions provide the direction in which to proceed with future testing.

The frangible connection concept using light weight stiff members and aluminum bolts is the best solution to meet the immediate requirements for an MLS support structure. It is admittedly not the best design for frangibility, however the concepts are consistant with the general requirements of low mass, short length and low toughness members. The design has the distinct advantage of using readily available materials and established manufacturing processes, plus it can be analysed to meet strength and deflection requirements.

The frangible member concept should ultimately produce the best frangible design. The use of frangible members in the support structure will permit more control over the location of fracture and level of energy absorbed on impact. Glass fiber reinforced plastic material is light weight and brittle, and can be fabricated into various structural shapes. Members can have pre-designed break points to permit fragmented separation and minimum energy absorbtion. An extensive test program should be established to evaluate different fiber reinforced plastics, and to test methods of incorporating break points along the length of the member. The test program will be required to establish strength and deflection parameters for the material and should examine ways of building in break points which will not propogate under cyclic wind loading. The selected material and design should be subjected to full scale, fully instrumented impact tests using an impactor more respresentative of the aircraft velocity and mass.

APPENDIX A

Literature Search of Reference Material

A literature search of material related to the project was carried out at the start of the study. The search covers conventional reference sources as well as a retrospective computer search of several different databasis. A survey of published literature and reference material is included below.

* 1. Harralson R., Laible C., Lazarin J.- "Development and Test of Low Impact Resistance Structures", Volume 1, ASE Inc., February 1974.

2. Laible C., Lazarin J.- "Development and Test of Low Impact Resistance Structures, Installation of Approach Lighting System at Runway 31, NAFEC", ASE Inc., June 1976.

3. Rogers E., Ross J. Snyder K.- "Development and Test of Low Impact Resistant Towers", Permali Inc., August 1979.

* 4. FAA-ER-530-81-04- "Structural/Mechanical Design Requirements For Low Impact Resistance Microwave Landing System Structures", FAA December 1982.

5. FAA-E-2702- "Low Impact Resistant Structures", FAA, May 1979.

* 6. Clough R., Penzien J.- "Dynamics of Structures", McGraw-Hill 1975.

7. Texas Transportation Institute.- "Safety Provisions for Support Structures on Overhead Sign Bridges", Technical Memorandum 605-4.

8. U.S. Department of Transportation,- "Dynamic Tests of Break-Away Lighting Standards Using Small Automobiles", January 1976.

9. Highway Research Board- "Development of Design Criteria for Safer Luminaire Supports", Report #77.

* Material directly related to frangibility and this report.

10. American Society of Civil Engineering- "Structural Analysis & Design of Nuclear Power Plant Facilities", ASCE Book 58.

11. Sachs P.- "Wind Forces in Engineering" Pergamon Press, 1978.

12. Hoerner I.- "Fluid-Dynamic Draw", Hoerner, 1958.

13. Davenport A.G.- "Wind Loads on Structures", National Research Council, TP 88, March 1960.

14. Transport Canada- "General Specification for Electronic Procurement of Electronic Equipment", Specification DFS 1000, April 1985.

15. Canadian Standards Association- "Antenna Towers and Antenna - Supporting Structures", CSA Standard S37-M1981.

16. Alcan Canada Products Limited- "Strength of Aluminum" Alcan, April 1973.

17. The Aluminum Association Incorporated- "Engineering Data For Aluminum Structures", Aluminum Association January 1975.

18. Fiberglass Limited- "Design Data Fibreglass Composites".

19. American Society for Testing and Material- "Annual Book of ASTM Standards, ASTM 1986.

APPENDIX B

LIST OF CONTACTS

The following list provides the name and organization of persons able to supply information related to the subject matter of this report.

1. Mr. Stephen A. Cannistra - Federal Aviation Administration; Extensive design experience in frangible structures for FAA.

2. Dr. P. Fertis - Akron University; Breakaway structures design for NASA.

3. Mr. Alan Carr - Carr-Sawyer Inc; Design of frangible towers.

4. Dr. Tarek Aziz - Atomic Energy of Canada Limited: Expert in structural dynamics.

5. Dr. Tony Firmin - H.G. Engineering Ltd
Computer analysis of frangible structures.

6. Mr. Richard Sauve - Ontario Hydro;
Computer program development.

7. Ms. Suzanne Frogley - Aviation Safety Research and Analysis, DOT; Aircraft accident statistics

8. Mr. Mark Smith - Air Navigation Technolgy Development, DOT; Risk analysis of aircraft impact.

9. Mr. Merv Utas - Air Navigation Policies and Standards DOT; Aerodrome polices/standards for operational requirements and frangibility.

10. Mr Gunar Janitens - Airport Facilities, Building Structures,
DOT; ILS building design.

11. Mr. E.d Alf - Airport Facilities, Utilities, DOT;
Approach lighting structures design.

APPENDIX C

STRUCTURAL ANALYSIS OF MLS SUPPORT STRUCTURE AND SIMULATED AZIMUTH ENCLOSURE.

TABLE OF CONTENTS

SECTION		PAGE NO.
1.	BACKGROUND	C-1
2.	INTRODUCTION	C-1
3.	ENCLOSURE AND TOWER MODEL	C-1
	3.1 ASAS Finite Element Model	C-1
	3.2 Nodal Geometry	C-3
	3.3 Section Properites	C-4
4.	ENVIRONMENTAL DESIGN LOADS	C-5
	4.1 Load Cases	C-5
	4.2 Wind Loads	C-6
	4.2.1 Tower	C-6
	4.2.2 Enclosure	C-8
	4.3 Ice Loads	C-9
	4.3.1 Tower	C-9
	4.3.2 Enclosure	C-10
5.	OPERATING DEFLECTIONS	C-11
6.	FOUNDATION LOADS	C-14
7.	STRESS ANALYSIS	C-15
	7.1 Allowable Stresses	C-15
	7.2 Member Stresses	C-16
	7.3 Stress Summary	C-19

1. Background

This report serves as the engineering documentation package for the MLS Support Tower and the Simulated Azimuth Enclosure. The contents herein fulfill the requirements of section 5.5 of the Statement of Requirements provided in DSS contract T8200-6-6520/01-NG.

2. Introduction

The tower is designed for use in supporting the Hazeltine 2 deg. beamwidth azimuth antenna or the Andrew simulated azimuth enclosure. The tower consists of three modular units which enable the MLS equipment to be raised in one metre increments to a total height of three metres. Frangibility concepts are incorporated in the design by the use of short length, light weight, stiff members, bolted together with brittle aluminum fasteners.

Analysis of the support structure accomplished through the use of the ASAS [1] finite element modelling program. The results presented in this report show that the structure satisfies both the stiffness and strength requirements for operating and survival environmental conditions specified in DFS 1000[2], for Class 2 Outdoor Equipment.

3. Enclosure and Tower Model

3.1 ASAS Finite Element Model

The finite element model for the azimuth enclosure and support structure is shown in figure 3.1. Tower members are represented by elements with the same physical properties as the structural aluminum sections they are fabricated from. The enclosure is represented by rigid elements with no mass density. The self weight and wind loads of the enclosure are transfered to the tower as discrete nodal loads.

(1) Atkins Structural Analysis System (ASAS). Kins Development Ltd; Epsom, England.

(2) General Specification for Procurement of Electronic Equipment, DFS 1000, First Edition.

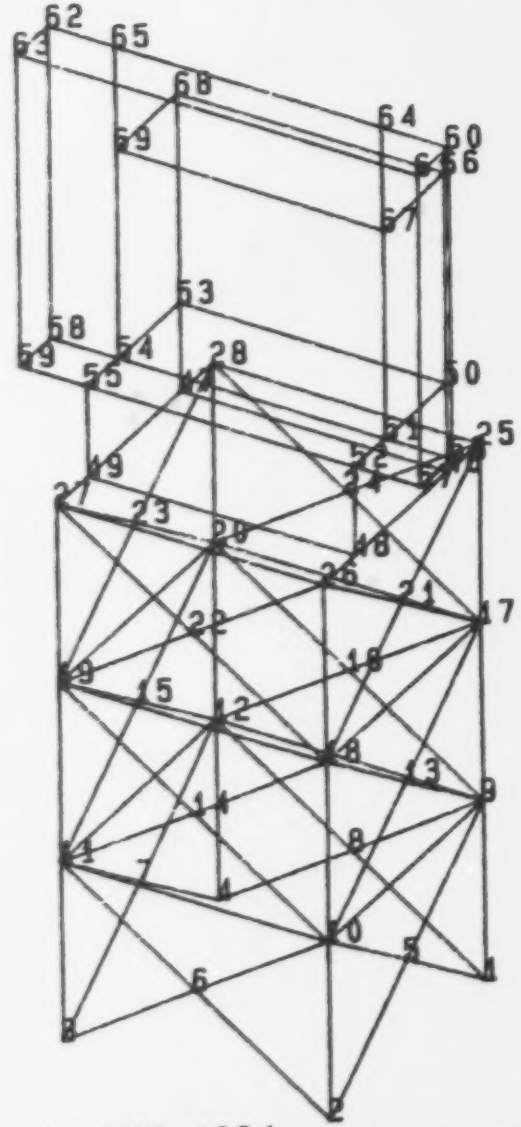
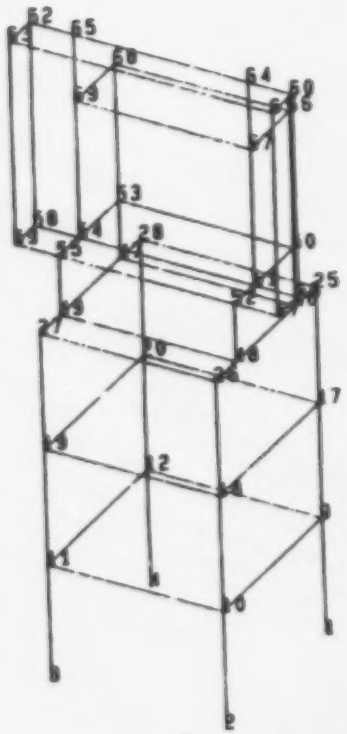
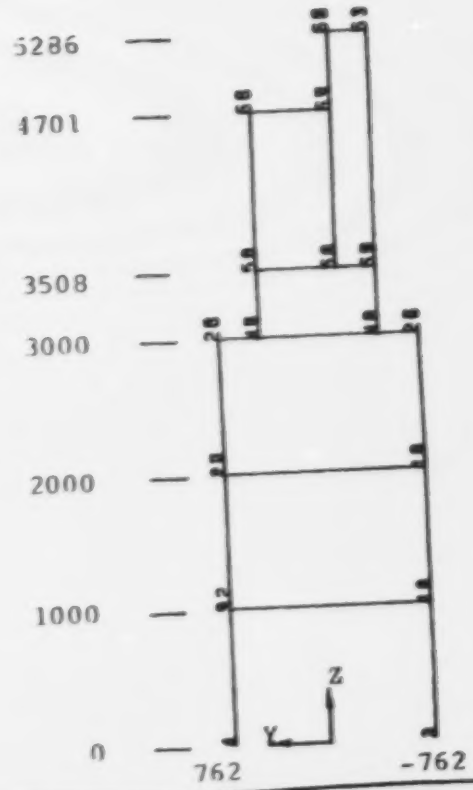


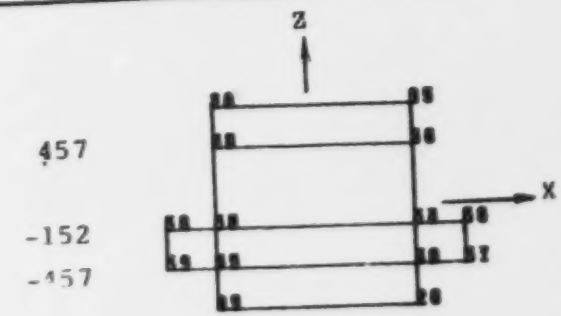
FIG. 3.1 Finite Element Model - Enclosure and Tower

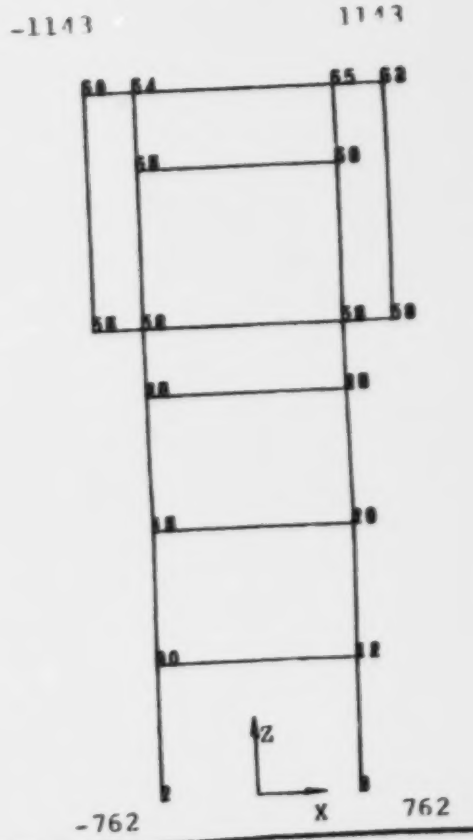
3.2 NODAL GEOMETRY

(dimensions in mm)









3.3 Section Properties

DESCRIPTION	ELEMENT	AREA mm^2	I_z $10^3 mm^4$	I_y $10^3 mm^4$
TOWER LEG 3x3x1/4 ANGLE	BEAM	935	520	520
HORIZONTAL 2 1/2x1 1/2x 3/16 ANGLE	FLA2	465	191	54
SUPPORT CHANNEL 6 x 2 1/2	BEAM	1929	6839	728
CROSS BRACE 2 1/2x1 1/2 x 3/16 ANGLE	BM3D	465	191	54
ENCLOSURE	BEAM	6450	41623	41623

4. ENVIRONMENTAL DESIGN LOADS

4.1 Load Cases

ASAS MODEL	LOAD CASE	SELF WEIGHT	WIND DIRECTION	WIND VELOCITY km/h	ICE THICKNESS cm
FTR1	1	INCL	-	-	-
	2	INCL	FRONT	175	
	3	INCL	OBLIQUE	175	
	4	INCL	FRONT	213	
	5	INCL	OBLIQUE	213	
FTR2	1	INCL	-	-	5.0
	2	INCL	FRONT	124	5.0
	3	INCL	OBLIQUE	124	5.0
	4	INCL	FRONT	151	5.0
	5	INCL	OBLIQUE	151	5.0

4.2. Wind Loads:

4.2.1. Tower

frontal area: (no ice)

legs 3" X 3" X 1/4" = 3" X 39" X 6 = .453m^2

horiz 2 1/2" X 1 1/2" X 3/16" = 2 1/2" X 53" X 3 = .257m^2

diag 2 1/2 X 1 1/2" X 3/16" = 2 1/2" X 29" X 12 = .561m2

A = 1.271m^2

(13.7ft^2)

frontal area: (with ice)

legs 7" X 39" X 6 = 1.06m^2

horiz 6 1/2" X 53" X 3 = .67m^2

diag 6 1/2" X 29" X 12 = 1.46m2

A = 3.19m^2

(34.3ft^2)

static wind pressure:

$q = 1/2 \rho V^2 = 5.13X10^{-5}V^2$ (V in km/hr)

$p = qC_p$ (q in kPa)

C_p = 1.5 without ice CSA S37

1.2 with ice

Where: q = reference velocity pressure

p = design wind pressure

C_p = shape factor

pressures for design wind velocities:

	V(km/hr)	q(kPa)	p(kPa)
Operating (No Ice)	175	1.57	2.35
Operating (With Ice)	124	.79	.94
Survival (No Ice)	213	2.29	3.43
Survival (With Ice)	151	1.14	1.37

total tower load:

$F_t = 2 \times P \times A$ CSA S37

	TOTAL	LOAD DISTRIBUTION - NODES F_y					
	Ft kN	10 $1/4F_t$	11 $1/4F_t$	18 $1/6F_t$	19 $1/6F_t$	26 $1/12F_t$	27 $1/12F_t$
Operating (no ice) FTR1 L.C.2 & L.C.3	5.97	1.49	1.49	1.00	1.00	.50	.50
Operating (with ice) FTR2 L.C.2 & L.C.3	6.00	1.50	1.50	1.00	1.00	.50	.50
Survival (no ice) FTR1 L.C.4 & L.C.5	8.71	2.18	2.18	1.45	1.45	.73	.73
Survival (with ice) FTR2 L.C.4 & L.C.5	8.74	2.19	2.19	1.46	1.46	.73	.73

4.2.2. Enclosure

frontal area: $A = 2.3 \times 1.8 = 4.14m^2$ $(44.5ft^2)$

assumed same for ice and no ice cases.

drag and yaw on flat rectangular surface:

front wind $F_t = q \times A \times Cd$ $Cd = 1.2$

oblique wind $F_t = q \times A \times Cd$ $Cd = 1.0$

(wind angle 50^o)

$M_t = q \times A \times L \times Cy$ $Cy = .13$

total enclosure loads:

	TOTAL		LOAD DISTRIBUTION - NODES Fy			
	F_t kN	M_t kN.m	57	61	59	63
Operating (no ice)						
FTR1 L.C.2 -Front wind	7.76	0	1.94	1.94	1.94	1.94
FTR1 L.C.3- Oblique wind	6.47	1.93	2.04	2.04	1.20	1.20
Operating (with ice)						
FTR2 L.C.2 - Front Wind	3.88	0	.97	.97	.97	.97
FTR2 L.C.3 - Oblique wind	3.23	.97	1.02	1.02	.60	.60
Survival (no ice)						
FTR1 L.C.4 - Front Wind	11.35	0	2.84	2.84	2.84	2.84
FTR1 L.C.5 - Oblique wind	9.46	2.83	2.98	2.98	1.74	1.74
Survival (with ice)						
FTR2 L.C.4- Front Wind	5.68	0	1.42	1.42	1.42	1.42
FTR2 L.C.5- Oblique Wind	4.73	1.41	1.49	1.49	.87	.87

4.3. Ice Loads:

4.3. 1 Tower

ice density ρ_i = 8.80 kN/m^3 (56lbs/ft^3)
ice thickness t_i = 5 cm radial (2.0")

in the computer model, ice weight is simulated by increasing the density of the structural member; this makes the member appear heavier but keeps the stiffness of the metal area.

density of metal + ice $\rho_{m+i} = \rho_m + \frac{A_i}{A_m}(\rho_i)$

where density of aluminum = 26.6kN/m^3 (169 lbs/ft^3)

A_m = area of aluminum
A_i = area of radial ice

3"X3"X1/4" Angle

A_m = 9.35 cm^2
A_i = 17.8X5+2(12.7X5)+7.62X5=258cm^2
ρ_{m+i} = 26.6+ 9.35 (8.8) = 266 kN/m^3

similarly 2 1/2" X 1 1/2" X 3/16" Angle ρ_{m+i} = 413 kN/m^3
6" X 2 1/2" Channel ρ_{m+i} = 195 kN/m^3

4.3.2. Enclosure

-assume ice forms on entire surface area of enclosure

surface area

1. front 1.8X2.3 = 4.14 m^2
2. side 2X1.8X.3 = 1.08 m^2
3. top 2.3 X .3 = .69 m^2
4. back 2X1.8X.4 = 1.44 m^2
   .6 X 1.5 = .90 m^2
5. doors 1.2 X 1.5= 1.80 m
6. sides 2X 1.2X.6= 1.44 m^2
7. top .6 X 1.5 = .90 m2

12.39 m^2

ice weight = 8.8kN/m^3 X .05m X 12.39 m^2

= 5.45 kN (1225 lbs)

total weight = 5.34 + 5.45 = 10.79 kN (2426 lbs)
(enclosure + ice)

load distribution: Node 46, 47, 48, 49

F_z = -2.70 kN (-606 lbs)

5. Operating Deflections

Angular rotations at the base of the MLS enclosure are provided for operating wind conditions with and without ice. The direction of rotation is shown in figure.5.1. In all cases, both the pitch and yaw deflections are within the maximum allowable limits of $.1^{o}$ and $.01^{o}$ respectively.

MODEL DESCRIPTION	LOADS (TOWER+ENCL.)			DEFLECTION	
	F_y(kN)	F_z(KN)	M_z(kN.m)	PITCH (DEG.)	YAW (DEG.)
FTR1 L.C.2 Front Wind 175kMH no ice	13.74	-6.53	0	.033	0
FTR1 L.C.3 Oblique Wind 175 kMH no ice	12.45	-6.53	1.93	.029	.0076
FTR2 L.C.2 Front Wind 124 kMH 2" Radial Ice	9.91	-26.29	0	.019	0
FTR2 L.C.3 Oblique Wind 124 kMH 2" Radial Ice	9.27	-26.29	0.97	.017	.0036

Rotation at the base of the enclosure is calculated from displacements given in the ASAS output as follows:

$$\text{PITCH} = \tan^{-1} \frac{DZ_{46} - DZ_{48}}{36}$$

$$\text{YAW} = \tan^{-1} \frac{DY_{46} - DY_{47}}{60}$$

where DZ_n, DY_n, are the deflection in inches in the Z and Y directions at node N.

Both the pitch and yaw deflections are less than the maximum allowable values of .1 deg and .01 deg respectively. Wind loads which would produce rotation about the y axis are significantly lower than loads producing pitch and are therefore not considered in the analysis

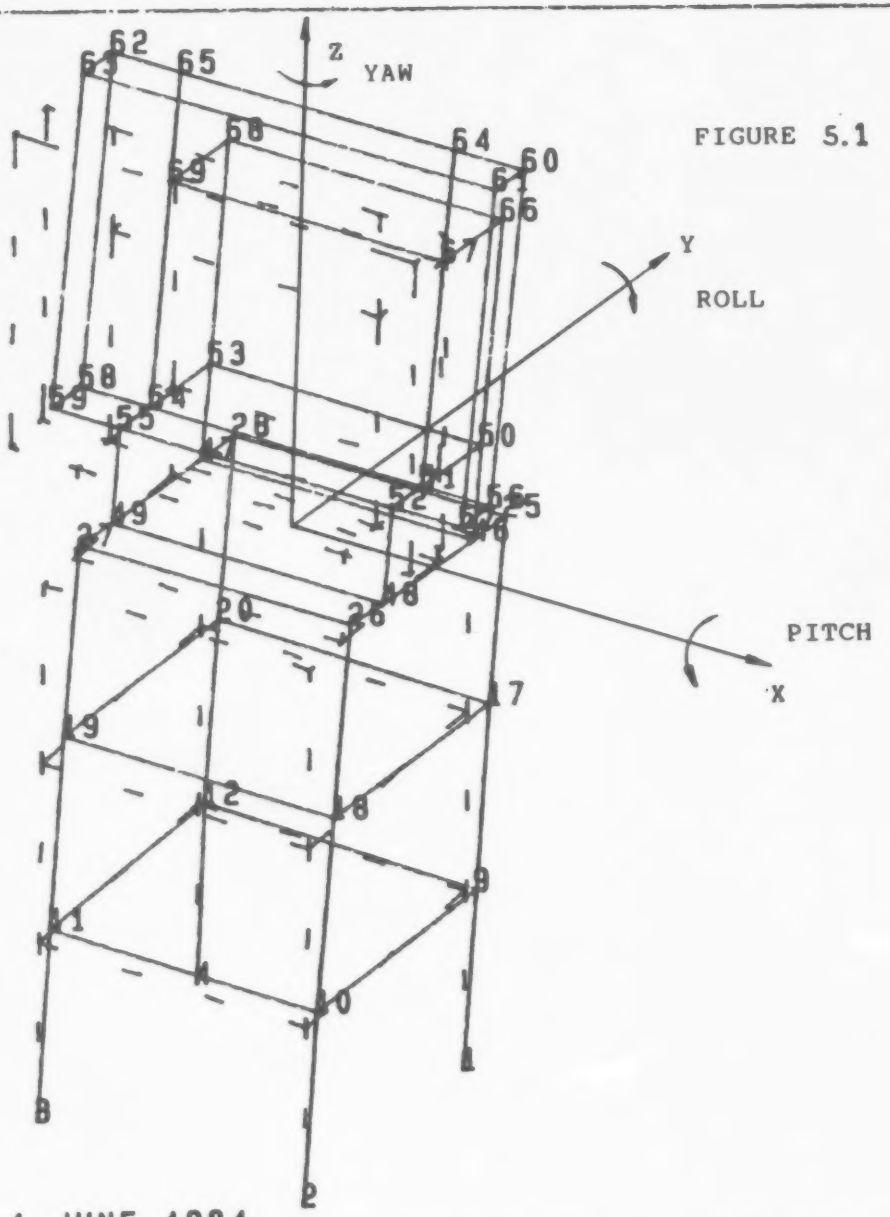

Z
YAW
Y
ROLL
PITCH
X
DASH LINE - ORIGINAL SHAPE
SOLID LINE - DEFLECTED SHAPE

FIGURE 5.1

6. FOUNDATION LOADS

Foundation loads for the survival wind conditions are provided below. These numbers include 5.34kN for the weight of the azimuth antenna plus 1.19 kN for the weight of the tower

DESCRIPTION	FORCE	LOAD AT NODE NUMBER (kN)			
		1	2	3	4
FTR1 L.C.4	F_x	1.71	-1.45	1.45	-1.71
Front Wind V=213kMH	F_y	5.36	4.76	4.76	5.36
No Ice	F_z	-23.21	19.93	19.93	-23.21
FTR1 L.C.5	F_x	1.03	-.78	1.70	-1.95
Oblique Wind V=213kMH	F_y	5.35	4.73	3.79	4.40
No Ice	F_z	-20.76	17.49	16.80	-20.06
FTR2 L.C.4	F_x	1.58	-.31	.31	-1.58
Front Wind V=151kMH	F_y	4.44	2.80	2.80	4.44
5.0cm Radial Ice	F_z	-19.79	6.65	6.65	-19.79
FTR2 L.C. 5	F_x	1.24	.04	.43	-1.71
Oblique Wind V=151kMH	F_y	4.43	2.80	2.32	3.96
5.0 cm Radial Ice	F_z	-18.57	5.42	5.07	-18.21

Foundations should be designed in accordance with local soil conditions and be capable of carrying the maximum loads as given above. The minimum requirements for permanent foundations would be 150mm dia. sono tube filled with 20MPa concrete to a depth at least 1.2m below grade level. Temporary foundations such as removable steel footings or a weighted steel interface frame should be designed to resist the maximum uplift on each leg.

7. Stress Analysis

7.1. Allowable Stresses

Allowable stresses provided in the following table are based on the requirements of standard CSA S157 - The Structural Use of Aluminum in Buildings. All tower members are fabricated from 6061-T6 aluminum and all bolts are 2024-T4 aluminum.

6061-T6	Ultimate Strength	262	MPa
	Yield Strength	241	MPa
	Elastic Modulus	$69X10^3$	MPa
	Density	26.6	kN/m^3
2024-T4	Ultimate Strength	427	MPa
	Yield Strength	275	MPa
	Elongation in 2"	10	%

PROPERTY	ALLOWABLE STRESS (MPa)	
	6061-T6	2024-T4
TENSION	131	165
COMPRESSION $\lambda < 63.4$ $\lambda > 63.4$	 $148-.958\lambda$ $3.44X10^5/\lambda^2$	 - -
SHEAR	78.6	107
BENDING	144	-
BEARING	209	-

7.2 MEMBER STRESSES

Stresses for members and connections are calculated from loads generated by the computer model. Resultant stresses are compared against the allowable stress and the ratio is the reserve factor. (R.F.).

$$R.F. = \frac{\text{Allowable Stress}}{\text{Actual Stress}}$$

The minimum permissible reserve factor is 1.0.

TOWER LEGS:

3 X 3 X 1/4 Angle — Max. Tension = 15.8 kN

$A = 935\ mm^2$ — Max. Compression = 18.5 kN

$S = 9.5 \times 10^3 mm^3$

$r = 15$ mm

$L = 1.0$ m

i. Column Load $f_c = 18.5/935 = 19.8$ MPa

Slenderness $\frac{KL}{r} = \frac{1000}{15} = 66.7$

Allowable $F_c = 3.44 \times 10^5/66.7^2 = 77.2$ MPa

$R.F. = 77.2/19.8 = 3.9$

ii. Bolt Load — Max. Shear = f_v = 26.2 MPa

5/8" Dia 2024-T4 — Max. Tension f_t = 103.4 MPa

Combined Shear and Tension $(f_v/F_v)^2 + (f_t/F_t)^2 \leq 1$

$(26.2/107)^2 + (103.4/165)^2 = .45$

$R.F. = 2.2$

HORIZONTAL MEMBERS:

2 1/2 x 1 1/2 x 3/16 angle — Max. Tension = 2.3 kN

$A = 465\ mm^2$ — Max. Compression = 1.9 kN

r = 8.4 mm

L = 1403 mm

i. Compression $f_c = 1.9/465 = 4.1$ MPa

$\frac{KL}{r} = 1403/8.4 = 167$

$F_c = 3.44 \times 10^5/167^2 = 12.3$ MPa

R.F = 12.3/ 4.1 = 3.0

ii. Bolt Shear

1/2" Dia 2024-T4 $f_v = 17.9$ MPa

R.F. = 107/17.9 = 6.0

TOP SUPPORT CHANNEL:

6 x 2 1/2 channel — Max. Bending P = 3.11 kN

$A = 1929\ mm^2$ — $M_x = 1932$ kN.mm

$S_x = 89.8 \times 10^3 mm^3$ — $M_z = 18.1$ kN.mm

$S_y = 16.1 \times 10^3 mm^3$

i. Bending $f_b = (3.11/1929)+(1932/89.8x10^3)+(18.1/16.1x10^3) = 24.4$MPa

R.F. = 144/24.4 = 5.9

ii. Bolt Shear

1/2" dia 2024-T4 $f_v = 36.9$MPa

R.F. = 107/36.9 = 2.9

VERTICAL CROSS BRACE

2 1/2 x 1 1/2 x 3/16 Angle — Max. Tension = 5.69 kN

$A = 465\ mm^2$ — Max Compression = -6.45 kN

r = 8.4 mm

L = 1613 mm

i. Compression $F_c = 6.45/465 = 13.9$ MPa

Slenderness .45 x 1613/8.4 = 86.4
(k=.45 for cross brace)

Allowable $F_c = 3.44 \times 10^5/(86.4)^2 = 46.1$ MPa

R.F. = 46.1/13.9 = 3.3

ii. Bolt Shear $f_v = 50.9$ MPa

R.F. = 107/50.9 = 2.1

7.3 STRESS SUMMARY

COMPONENT	STRESS TYPE	STRESS MPa	RESERVE FACTOR
TOWER LEGS	COMPRESSION	19.8	3.9
	BOLT SHEAR	26.2	
	BOLT TENSION	103.4	2.2
HORIZONTAL MEMBERS	COMPRESSION	4.1	3.0
	BOLT SHEAR	17.9	6.0
TOP SUPPORT CHANNEL	BENDING	24.4	5.9
	BOLT SHEAR	36.9	2.9
CROSS BRACE	COMPRESSION	13.9	3.3
	BOLT SHEAR	50.9	2.1

APPENDIX D

INSTALLATION INSTRUCTIONS FOR SUPPORT STRUCTURE (P/N 171323)

Support Structure Installation Instructions

1. General

The MLS support structure is used to raise the azimuth enclosure to a height of 1, 2 or 3 metres above ground level. The structure consist of a top section which interfaces with the simulated azimuth enclosure, and two lower sections which are used to raise the top section in one metre increments. Weight of the top section is 125 lbs. Weight of each lower section is 80 lbs.

The complete structure can be assembled by two people in less than 2 hours. For the first assembly it is recommended that the entire structure be assembled to ensure alignment of sections, then tightened to lock the shape. The height can then be varied by removing one or both of the lower sections as complete units. Install all bolts with the nut on the outside and leave them finger tight. Once all hardware is installed, proceed to tighten by torquing 1/2" bolts to 25 ft. lbs and 5/8 bolts to 50 ft. lbs.

All fasteners have been rolled in tool saver bees wax to prevent the nut from binding on the bolt. If the tower is assembled several times it may be necessary to apply more wax to the threads. A tube of tool saver wax has been supplied for this purpose.

Tools required for assembly are:

-Torque wrench 50ft. lb capacity
-3/4" & 15/16" sockets
-3/4" & 15/16 wrench - 2 clamps or vise grips.

2. Assembly of Lower Sections

Refer to dwg. 171325 for assembly of the two lower sections. To assemble one face, lie two vertical legs (171329) on a flat surface and attach the horizontal angle (171330) to the top holes in the leg. Use 1/2" x 1 1/4" bolts and install them so that the nut is on the outside of the tower. Attach the four diagonal angles (171338) to the legs and to the plate (171339). Repeat this for the opposite face then stand both assemblies upright roughly 60" apart. Join the two faces using the two remaining horizontal angles and bolting them to the top holes in the legs. Pre-assemble the diagonal angles to the joining plate then attach the two top diagonals to the legs followed by the two lower diagonals to pull the sections into the right shape. Repeat this for the opposite face to complete the section. The four bolts joining the diagonals to the plate should be tightened as follows; place one of the spare diagonal angles across two diagonals so that they form a straight member (see figure 1.), hold or clamp the angle in place and tighten bolt #1, remove the angle and place it across the other two diagonals and tighten bolts #2 and #3, put the angle back across the first diagonals and tighten bolt #4. Repeat this for all faces of the section. Do not tighten any other bolts at this time.

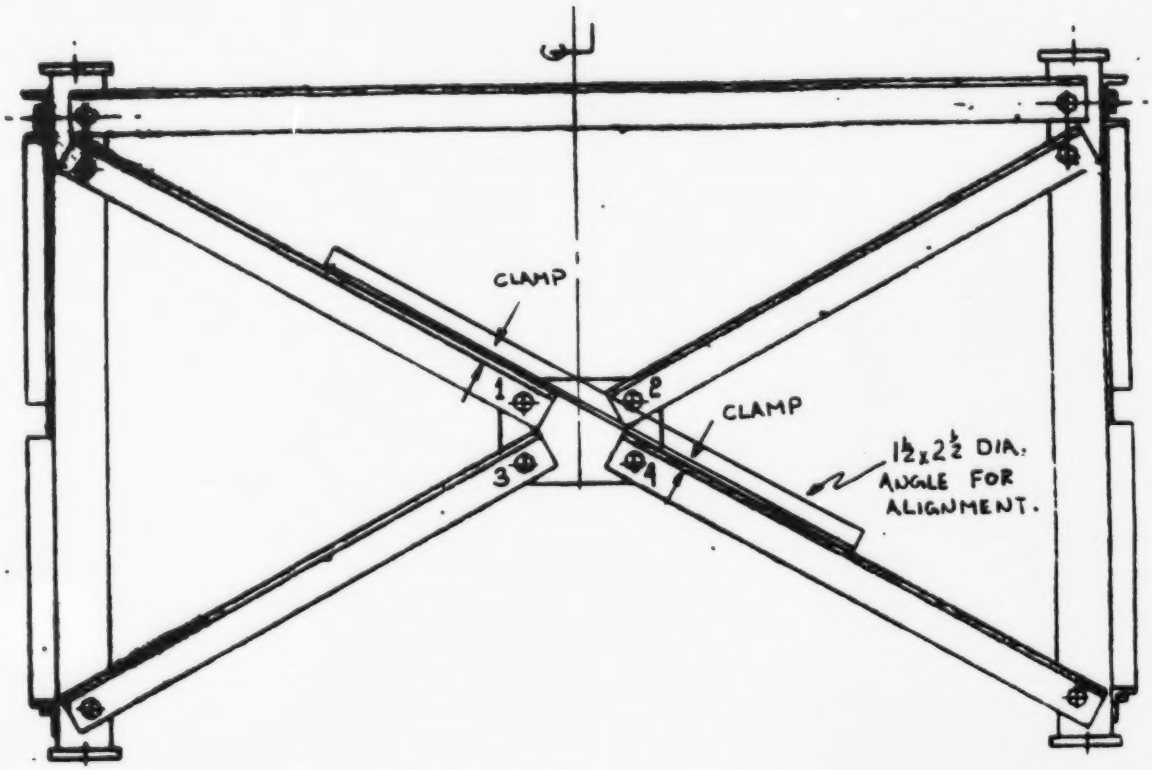
3. Assembly of Top Section

Refer to dwg. 171324 for the top section assembly. The procedure is almost the same as for the lower section except that two 6" channels are used in place of two horizontal angle members. Lie the channels (171331) face down and place one vertical leg at each end. Use 1/2 x 1 1/4" bolt through the top hole in the leg and 1/2" x 1 3/4" bolt through the bottom hole which fastens the channel, leg, and diagonal angle. Complete the assembly of the diagonals then stand up the two faces and join them with the two horizontal angles. Assemble the remaining diagonals and tighten the plate bolts as per section 2. Two 4" support channels (171332) are mounted face down across the two 6" channels using 5/8" x 3 1/4" bolts and spacers (171345).

4. Tower Assembly

Tower assembly is shown in dwg. 171323. Place one of the lower sections on the foundation bolts (or other fixture used to support the tower). Lift the second section and place it on top of the first then drop the four 5/8" x 1 1/2" bolts into the holes in the end plates of the legs. Diagonal bracing members (171328) are installed between the interface of each of the sections. One angle mounts across corners on the underside of the leg end plates and the other angle mounts across the other two corners and sits on top of the leg end plates. Use 1/2" x 1 3/4" bolts at the ends of the diagonals and 1/2" x 1 3/4" bolt and spacer 171346 at the centre hole joining the diagonals.

FIGURE 1.



APPENDIX E

INSTALLATION INSTRUCTIONS FOR

SIMULATED AZIMUTH ENCLOSURE (P/N 171300)

APPENDIX E

Installation Instructions for Simulated Azimuth Enclosure (P/N 171300)

1. General

The simulated azimuth enclosure consists of four main components:

1. base structure	171291	- 95 lbs
2. enclosure	171273	- 283 lbs
3. detachable outer panels	171293 Qty (2).	- 48 lbs ea

The base structure and enclosure simulate a Hazeltine 2° beamwidth antenna. Attachment of the two outer panels expands the enclosure to simulate the 1° beamwidth Hazeltine antenna. The detachable panels use aluminum mesh as their reflective surface minimizing wind loading on the structure. The base structure has the same interface as the Hazeltine antenna making the two interchangeable with the foundation or support structure. Tools required for assembly are: 7/16" and 3/4" wrench 1-1/8" wrench or adjustable wrench, phillips screwdriver.

2. Enclosure/Base Structure Assembly

The enclosure is attached to the base support with six 1/2" x 4" long bolts. Remove the base from the shipping crate and place it on a flat surface. The face with six 1/2" dia. holes in the channels should be up, and the side with the four 3/4" dia. holes should be down. Remove the enclosure from the packing crate and place it on top of the base structure so that the holes in the tubes at the bottom of the enclosure align with the six holes in the top of the base structure. Fasten with nut lock washer and flat washer. The enclosure can be lifted by four men or by using a fork lift or crane and lifting with slings from the two lifting plates behind the front part of the enclosure.

3. Mounting To Support Structure

The enclosure and base structure assembly mounts to the support structure using four 3/4 x 9" long threaded rods. Fasten the threaded rods to the top of the support structure using hex nuts and lock washers, then use hex and jam nuts to support the enclosure (see detail A dwg.171360) The nuts can be adjusted up or down to level the enclosure. The length of threaded rod between the upper and lower sets of nuts should be a minimum of 1" and maximum 2".

4. Installation of Outer Panels

The outer panels are numbered and attached to the correspondingly numbered side of the enclosure. Align the protruding angles on the end of the panel with the open tubes on the enclosure. Push the panel in until the 1/2" holes line up and insert the 4 - 1/2" x 4" bolts. A braided strap is provided to assure electrical continuity between the panel and the main body of the enclosure. One strap is attached across the top and bottom joint of each panel using 1/4 dia. bolts screwed into the threaded inserts located on each side of the joint.

5. Installation of Obstruction Lighting

Bolt the conduit and attached outlet to the rear left hand side of the enclosure. The conduit is held to the enclosure by two mounting clips and the outlet is bolted to the angle bracket at the bottom of the enclosure.
Mount the obstruction light to the top of the conduit and lock in place with the set screw. Connect the colour coded wires from the conduit to those inside the obstruction light.